



Northeast Fisheries Science Center Reference Document 11-13

Description of the 2009 Oceanographic Conditions on the Northeast U.S. Continental Shelf

by Paula S. Fratantoni, Tamara Holzwarth-Davis,
Cristina Bascuñán, and Maureen H. Taylor

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TABLE OF CONTENTS

Table of Contents.....	i
List of Tables	i
List of Figures.....	i
List of Appendix Tables.....	iii
Abstract.....	iv
Introduction.....	1
Data and Methods	1
Results.....	3
References Cited.....	5

LIST OF TABLES

Table 1. Listing of 2009 NOAA Northeast Fisheries Science Center cruises supported by the Oceanography Branch.....	6
Table 2. The 2009 regional average surface and bottom temperature values computed from CTD data that were sorted into six 2-month time periods for the five regions of the Northeast U.S. continental shelf shown in Figure 1.....	7
Table 3. The 2009 regional average surface and bottom salinity values computed from CTD data that were sorted into six 2-month time periods for the five regions of the Northeast U.S. continental shelf shown in Figure 1.....	8

LIST OF FIGURES

Figure 1. Region designations for the Northeast U.S. Continental Shelf. The 100 m and 200 m isobaths are also shown.....	9
Figure 2. The 2009 station distributions for each 2-month time period. The regional boundaries are also overlain. Contours indicate the 100 and 200-meter isobaths.....	10
Figure 3. Time series of the 2009 regional surface (left) and bottom (right) temperatures (blue) and anomalies (bars) as a function of calendar day. Error bars are indicated for the anomaly estimates. The error bars are determined from SDV1 in Table 2, incorporating the uncertainty in both the predicted and measured temperatures from a given region (see Holzwarth and Mountain, 1990).	11

Figure 4. Time series of the 2009 regional surface (left) and bottom (right) salinities (blue) and anomalies (bars) as a function of calendar day. Error bars are indicated for the anomaly estimates. The error bars are determined from SDV1 in Table 3, incorporating the uncertainty in both the predicted and measured salinities from a given region (see Holzwarth and Mountain, 1990). 12

Figure 5. Time series of the 2009 regional shelf water temperature, salinity, and volume as a function of calendar day shown in blue for the southern (left) and northern (right) Middle Atlantic Bight. Shelf water anomalies are shown by the vertical bars. 13

Figure 6a. Near-surface (top) and near-bottom (bottom) temperature (left) and salinity (right) distributions during January-February, 2009. Temperature and salinity are contoured in increments of 1°C and 0.5, respectively. The 34 isohaline is denoted by the heavier contour. 14

Figure 6b. Near-surface and near-bottom temperature anomaly (left) and salinity anomaly (right) distributions during January-February, 2009. Temperature and salinity anomaly are contoured in increments of 1°C and 0.5, respectively..... 15

Figure 7a. Near-surface (top) and near-bottom (bottom) temperature (left) and salinity (right) distributions during March-April, 2009. Temperature and salinity are contoured in increments of 1°C and 0.5, respectively. The 34 isohaline is denoted by the heavier contour..... 16

Figure 7b. Near-surface and near-bottom temperature anomaly (left) and salinity anomaly (right) distributions during March-April, 2009. Temperature and salinity anomaly are contoured in increments of 1°C and 0.5, respectively..... 17

Figure 8a. Near-surface (top) and near-bottom (bottom) temperature (left) and salinity (right) distributions during May-June, 2009. Temperature and salinity are contoured in increments of 1°C and 0.5, respectively. The 34 isohaline is denoted by the heavier contour..... 18

Figure 8b. Near-surface and near-bottom temperature anomaly (left) and salinity anomaly (right) distributions during May-June, 2009. Temperature and salinity anomaly are contoured in increments of 1°C and 0.5, respectively..... 19

Figure 9a. Near-surface (top) and near-bottom (bottom) temperature (left) and salinity (right) distributions during July-August, 2009. Temperature and salinity are contoured in increments of 1°C and 0.5, respectively. The 34 isohaline is denoted by the heavier contour..... 20

Figure 9b. Near-surface and near-bottom temperature anomaly (left) and salinity anomaly (right) distributions during July-August, 2009. Temperature and salinity anomaly are contoured in increments of 1°C and 0.5, respectively..... 21

Figure 10a. Near-surface (top) and near-bottom (bottom) temperature (left) and salinity (right) distributions during September-October, 2009. Temperature and salinity are contoured in increments of 1°C and 0.5, respectively. The 34 isohaline is denoted by the heavier contour..... 22

Figure 10b. Near-surface and near-bottom temperature anomaly (left) and salinity anomaly (right) distributions during September-October, 2009. Temperature and salinity anomaly are contoured in increments of 1°C and 0.5, respectively..... 23

Figure 11a. Near-surface (top) and near-bottom (bottom) temperature (left) and salinity (right) distributions during November-December, 2009. Temperature and salinity are contoured in increments of 1°C and 0.5, respectively. The 34 isohaline is denoted by the heavier contour..... 24

Figure 11b. Near-surface and near-bottom temperature anomaly (left) and salinity anomaly (right) distributions during for November-December, 2009. Temperature and salinity anomaly are contoured in increments of 1°C and 0.5, respectively..... 25

Figure 12. Monthly mean air temperature over the Northeastern U.S. for the years 1971-2000 (black) and 2009 (red), plotted from climate summary data compiled by the Northeast Regional Climate Center (<http://www.nrcc.cornell.edu>). The northeast region encompasses coastal states from Maine to Maryland and inland states west to West Virginia. 26

LIST OF APPENDIX TABLES

Appendix Table 1. The 2009 regional average temperature and salinity values for individual cruises that sampled within the western Gulf of Maine (boundaries defined in Figure 1.) Average values incorporating less than 10 observations are shown in gray. 27

Appendix Table 2. The 2009 regional average temperature and salinity values for individual cruises that sampled within the eastern Gulf of Maine (boundaries defined in Figure 1.) Average values incorporating less than 10 observations are shown in gray. 28

Appendix Table 3. The 2009 regional average temperature and salinity values for individual cruises that sampled within the Georges Bank area (boundaries defined in Figure 1.) Average values incorporating less than 10 observations are shown in gray. 29

Appendix Table 4. The 2009 regional average temperature and salinity values for individual cruises that sampled within the northern Middle-Atlantic Bight (boundaries defined in Figure 1.) Average values incorporating less than 10 observations are shown in gray..... 30

Appendix Table 5. The 2009 regional average temperature and salinity values for individual cruises that sampled within the southern Middle-Atlantic Bight, whose boundaries are defined in Figure 1. Average values incorporating less than 10 observations are shown in gray. 31

Appendix Table 6. The 2009 Temperature, salinity and volume of the shelf water in the Middle-Atlantic Bight during 2009. The shelf water is defined as water within the upper 100 meters having salinity less than 34. 32

ABSTRACT

Hydrographic observations from fourteen surveys spanning the Northeast U.S. Continental Shelf are combined into a descriptive overview of the broad-scale oceanographic conditions that were observed during 2009. Temperature and salinity observations are combined into six 2-month time periods in order to maximize both the spatial coverage of the data and its temporal resolution during the year. Maps of near-surface and near-bottom property distributions are presented for each bi-monthly period and time series of regional average properties are discussed for five geographic regions spanning the shelf: western Gulf of Maine (GOMW), eastern Gulf of Maine (GOME), Georges Bank (GBNK), and northern and southern Middle-Atlantic Bight (MABN and MABS, respectively). Surface conditions along the entire Northeast U.S. Continental Shelf were generally warm and fresh in 2009 relative to the reference period (1977-1987). The warmest/freshest waters were observed during the July/August time period with the largest anomalies occurring in the Middle Atlantic Bight. Near-bottom waters in the northern Middle Atlantic Bight were significantly fresher than normal early in the year, returning to normal values later in the year, while the opposite was true in the southern Middle-Atlantic Bight. Bottom temperatures trended warmer toward the end of 2009 from Georges Bank through the Middle-Atlantic Bight. While the annual average air temperature was slightly cooler than the long-term mean, the time of peak warming was shifted slightly later in the year. This may be partly responsible for the anomalously warm surface conditions observed in the Middle-Atlantic Bight at this time of year and for the enhanced warming that followed at depth in the near shore regions of the Middle Atlantic Bight. A Gulf Stream warm-core ring was responsible for anomalously warm and salty conditions observed over Georges Bank during the November/December period.

INTRODUCTION

The Northeast Fisheries Science Center (NEFSC) conducts multiple surveys on the Northeast U.S. continental shelf each year in support of its ongoing mission to monitor the shelf ecosystem and assess how its components influence the distribution, abundance, and productivity of living marine resources. In support of this mission, the Oceanography Branch provides conductivity, temperature and depth (CTD) instruments to all NEFSC cruises for the measurement of water column profiles of temperature and salinity. In addition to providing oceanographic context to specific field programs, these data contribute to a growing database of historical measurements that are used to monitor seasonal and interannual variability in the water properties on the northeast continental shelf.

Broad-scale surveys, sampling the shelf from Cape Hatteras, North Carolina, into the Gulf of Maine, are conducted up to six times per year during shelf-wide spring and fall bottom trawl surveys and on four dedicated seasonal Ecosystem Monitoring (EcoMon) surveys. Profiles of conductivity, temperature and depth are collected at each station on these shelf-wide surveys. Observations are also collected on other more regionally focused NEFSC surveys, where station coverage varies depending on the objectives of the particular field program. During 2009, hydrographic data were collected on 14 individual NEFSC cruises, amounting to 2093 profiles of temperature and salinity (Table 1). Here we present an annual summary of these observations, including surface and bottom distributions of temperature and salinity, as well as their anomalies relative to a consistent reference period. In addition, regional average values of temperature and salinity and their anomalies are computed for five different regions of the shelf during six bi-monthly periods. Finally, the volume and properties of the shelf water are examined for the Middle-Atlantic Bight region.

DATA AND METHODS

The Oceanography Branch provides CTD instrumentation and support to all NEFSC programs requesting this service. Training in instrument maintenance and operation, including deployment, data acquisition, recovery and preliminary processing, is provided as needed prior to sailing. On NEFSC surveys, CTD instruments are typically deployed in one of two modes: (1) during a bongo net tow, the CTD instrument is mounted on the conducting wire above the bongo frame and data are collected as a double oblique profile with the ship steaming at approximately 2 knots, (2) during a non-net tow, the CTD is mounted vertically on the wire and the sensors are soaked for one minute at the surface prior to descent. The sensors are not soaked at the surface prior to descent during bongo tows, rendering the upper 30 meters or more of the downcast unreliable. For this reason, the up-cast profile data are routinely processed as the primary data for each station.

In 2009, hydrographic data were collected aboard the NOAA ships *Delaware II* and *HB Bigelow*, and the R/V *HR Sharp* using a combination of Seabird Electronics SBE-19 and SBE-19+ SEACAT profilers and SBE 9/11 CTD units (Table 1). All raw CTD profile data were processed ashore, using standard Seabird Electronics software to produce 1-decibar averaged profiles in ascii-formatted files. Water samples were collected twice daily at sea during vertical casts. Following each cruise, these samples were analyzed using a Guildline AutoSal laboratory salinometer to provide quality control for the CTD salinity data. A salinity offset was applied to instrument data if the mean difference between the reference Autosal readings and the CTD

values exceeded ± 0.01 (a threshold chosen based on the expected instrument accuracy.) Vertical density profiles were examined for inversions due to bad conductivity or temperature readings and/or sensor misalignment. Egregious cases were replaced with a flag value. The processed hydrographic data were loaded into ORACLE database tables and made publically available via anonymous ftp (<ftp://ftp.nefsc.noaa.gov/pub/hydro>). Cruise reports have been prepared for each survey listed in Table 1 and are available online (<http://www.nefsc.noaa.gov/epd/ocean/MainPage>). Readers are referred to the individual cruise reports for notes, property maps and aggregate data specific to a particular survey.

Here, we aim to provide a descriptive overview of the hydrographic sampling that was conducted in 2009 and to characterize the broad-scale oceanographic conditions that were observed. In order to maximize both the spatial coverage of the data and its temporal resolution, the processed 2009 CTD data have been sorted into six 2-month time bins. Maps of near-surface and near-bottom temperature and salinity have been produced from profile data falling within each 2-month period. Surface fields include the shallowest observed temperature/salinity at each station that is also in the upper 5 meters of the water column, while bottom maps include the deepest observation at each station that also falls within 10 meters of the reported water depth. In order to examine the spatial and temporal variability over broader areas of the shelf, average values have been computed from the data within five sub-regions spanning the Northeast U.S. Continental Shelf (Figure 1). Regional averages have been computed for the bi-monthly binned fields (Tables 1 and 2) and for individual cruises (Appendix Tables 1-5).

In order to characterize variability that is not related to seasonal forcing, anomalies have been calculated at each station relative to a standard reference period (1977-1987). During this period the NMFS Marine Resources Monitoring and Prediction (MARMAP) program repeatedly occupied stations spanning the entire Northeast U.S. Shelf so that an annual cycle could be constructed for water properties across all regions of the northeast shelf (Mountain and Holzwarth, 1989; Mountain et al., 2004). The anomalies presented here are defined as the difference between the observed 2009 value at individual stations and the expected value for each location and time of year. Similarly, regional anomalies are the area-weighted average of these anomalies within a given domain. The methods used and an explanation of uncertainties is presented in Holzwarth and Mountain (1990).

Finally, we calculate the temperature, salinity and volume of the shelf water in the Middle-Atlantic Bight during 2009 and relate this to the conditions observed during the MARMAP reference period (Appendix Table 6). Following Mountain (2003), the shelf water mass is defined as water within the upper 100 meters having salinity less than 34. For each survey in 2009, the area of a sub-region was apportioned amongst its stations by an inverse distance squared weighting. The shelf water volume at a given station is the thickness of the shelf water at the station multiplied by its apportioned area, and the total shelf water volume within the sub region is the sum of these products for all stations within the region. Similarly, the average temperature and salinity was calculated in the shelf water layer at each station and multiplied by the total shelf water volume for that station. The sum of these products over all stations within a given sub-region, divided by the total shelf water volume for the region, determines the volume-weighted average temperature and salinity. Anomalies in the property and volume of the shelf water mass are calculated relative to like variables derived from MARMAP hydrographic data, as described above. Hence, here regional anomalies are computed as the mathematical difference between regional averages, *not* an average of the anomalies computed for a given sub-region.

RESULTS

Table 1 provides a listing of the NEFSC cruises that collected hydrographic data in 2009. In total, 2093 profiles of temperature and salinity were collected, processed and archived during the year. Combining the hydrographic data from multiple cruises into bi-monthly bins improves the spatial coverage compared with that of individual surveys, enabling us to examine the spatial and temporal patterns in hydrography over the region. Nonetheless, there are still significant gaps in several of the bi-monthly distribution maps shown in Figure 2, particularly in the Gulf of Maine during July/August, March/April, and September/October. These gaps result in part from a misalignment between the bi-monthly periods and the longer bottom trawl surveys that work from south to north along the shelf. The March/April and September/October periods encompass all but the final 10 days of the spring and 18 days of the fall bottom trawl surveys, respectively, when sampling was focused in the Gulf of Maine. The summer EcoMon survey would normally provide full coverage into the Gulf of Maine during the July/August period but was cut short due to an approaching tropical storm. Poor station coverage within the Gulf of Maine during July/August precludes the calculation of a representative regional average surface/bottom temperature and salinity value (Tables 2 and 3, Figures 3 and 4). Similarly, while the station coverage is better during the March/April and September/October periods, regional averages computed for the western and eastern Gulf of Maine are not true areal-averages, representative of the entire region, but are biased toward the southern portion of these sub-regions (Tables 2 and 3, Figures 3 and 4).

Overall, surface conditions along the entire Northeast U.S. Continental Shelf were warm and fresh in 2009 relative to the reference period (January/February being the exception; Figures 3 and 4). The warmest/freshest waters were observed during the July/August time period with the largest anomalies occurring in the Middle Atlantic Bight. Bottom properties were near normal in the Gulf of Maine, with salinity anomalies not significantly different from zero and bottom temperatures slightly warmer in the western Gulf of Maine throughout the year. By contrast, bottom waters in the northern Middle Atlantic Bight were significantly fresher than normal early in the year, returning to normal values later in the year, while the opposite was true in the southern Middle Atlantic Bight. Bottom temperatures trended warmer toward the end of 2009 from Georges Bank through the Middle Atlantic Bight. During 2009, the shelf water volume remained relatively high through a majority of the year, aside from a period of reduced volume in July-October, indicating that the shelf/slope front was consistently located offshore of its position during the MARMAP period (Figure 5).

Details related to the temporal trends in Figures 3 and 4 can be explored in the surface and bottom property distribution maps (Figures 6-11). Maps of near bottom salinity and salinity anomaly suggest that the trend from fresh to salty anomalies in the northern Middle Atlantic Bight time series may be related in part to an onshore shift in the shelf/slope front and to the influence of anticyclonic eddies in the adjacent slope water. Figures 9 and 10 suggest that the front, delineated by the $S=34$ isohaline, was located shoreward of its typical position between July/August and September/October in the northern Middle Atlantic Bight. This is reflected in the region of positive salty anomalies centered over the middle to outer shelf, accompanied by positive near-bottom temperature anomalies over the entire shelf (Figure 9b). The region of positive salinity anomaly (Figure 9b) occurs seaward of the shoreward meander in the 34 isohaline (Figure 9a), confirming that the shoreward shift in the front is not simply a seasonal

shift in the position of the front. This is substantiated by the minima in the shelf water volume anomaly observed during this same period (Figure 5). There is evidence in satellite-derived sea surface temperature maps that warm core eddies in the slope water may have contributed to the onshore movement of the front during this period. Multiple anticyclonic eddies were observed in the slope water, offshore of the 200 m isobath, during August and September. Several highly energetic features were present along the outer edge of the shelf (west of 69° W) during September-October, sandwiched between the shelf edge and two very large meanders in the Gulf Stream offshore. Warm/salty anomalies, aligned along the outer edge of the shelf at the surface in the Middle Atlantic Bight, coincide with the highly filamented inshore edge of these features (Figure 10b). Similarly, the dramatic warming and salinification that is observed over the full water column at Georges Bank during November/December (Figures 3 and 4; Figure 11) is caused by the prolonged influence of a very large warm core Gulf Stream ring impinging on the bank during this period. In contrast, the warm anomaly observed at the shelf edge in the southern Middle Atlantic Bight during this period is not caused by eddies or rings in the slope region. During this period, the Gulf Stream was free of meanders and the slope water was comparatively quiet west of 70° W.

Maps of near-bottom temperature show the seasonal formation of the cold pool in the Middle Atlantic Bight, with coldest temperatures observed during the May/June period (Figure 8a). The accompanying maps of near-bottom temperature anomaly suggest that temperatures in the cold pool were colder than normal, particularly in the region of the temperature minimum and along the southeastern edge of the pool (Figure 8b). By July/Aug (Figure 9) the cold pool has begun to weaken and warm. While the temperature anomaly near the core of the cold pool remains negative (indicating that temperatures here are colder than normal), a significant positive anomaly extends along the axis of the cold pool south of the core (indicating more warming than normal). By comparison, near-bottom temperatures are significant colder than the reference period inshore of the cold pool.

By September/October the entire near-shore region in the Middle Atlantic Bight was much warmer than normal (Figure 10b). This is consistent with historical observations in this region, which indicate that by late summer the effects of seasonal heating extend all the way to the ocean bottom in the near-shore regions (Castelao et al., 2010). It is not uncommon during this period for warmer waters to be found inshore of colder waters as is seen in Figure 10a (Mountain and Holzwarth, 1989). Seasonal heating does not penetrate to the bottom in deeper water, where gradients are larger due to the presence of the cold pool. However, the anomaly fields shown in Figure 10b suggest that this effect was more extreme than normal in late-summer 2009. Based on the climate summaries compiled by the Northeast Regional Climate Center (<http://www.nrcc.cornell.edu>), the annual peak in monthly average air temperature occurred slightly later in 2009 than the long-term mean (Figure 12). This timing is coincident with the largest surface temperature anomalies in the Middle Atlantic Bight (Figure 3), followed one month later by anomalous warming at the bottom (Figure 3 and Figure 10b). Overall, however, the annual mean air temperature across the Northeastern U.S. was 0.2°C below long term annual mean values.

According to the Northeast Regional Climate Center records, the annual mean precipitation over the Northeastern U.S. was 2.33" above the long-term mean (referenced to 1971-2000). In fact, 2009 was ranked the 5th wettest year out of the 115 preceding years. This could account in part for the fresh surface conditions observed throughout the region. However, a more thorough analysis would be needed to discriminate between local freshening due to

precipitation and river run-off and freshening due to advection from remote sources. For instance, while the regional average salinities in the eastern Gulf of Maine were only slightly fresh relative to the reference period at the surface, anomaly maps suggest that a saltier variety of near-bottom waters may have been entering the eastern Gulf of Maine through Northeast Channel and along the southwestern Scotian Shelf during May/June (Figure 8b). This roughly coincides with the period of maximum inflow to the Gulf of Maine at Cape Sable, Nova Scotia (Smith et al., 2001). These saltier source waters mix vertically with surface waters within the Gulf of Maine, including the near surface and inshore waters where freshening due to increased precipitation will be greatest.

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Table 1. Listing of 2009 NOAA Northeast Fisheries Science Center cruises supported by the Oceanography Branch.

Cruise	Program	Dates	Region(s)¹	Gear	Casts
DEL0901	NOAA/LMRCSC Coop.	15 – 21 Jan	South MAB	SBE-19	23
DEL0902	EcoMon Survey	26 Jan – 12 Feb	Full Shelf	SBE-19, 19+	169
HB0901	Spring Bottom Trawl	27 Feb – 8 May	Full Shelf	SBE-19	398
DEL0904	Coastal Shark Longline	15 Apr – 16 May	Southeast U.S.	SBE-19+	49
S10901	Scallop Survey	9 May – 2 Jul	MAB, GB	SBE-19+, 9/11	124
DEL0905	EcoMon Survey	27 May – 11 Jun	Full Shelf	SBE-19+	168
DEL0907	Cetacean Biology	15 – 28 Jul	West GOM	SBE-19+	20
DEL0908	Benthic Habitat	5 – 13 Aug	GB	SBE-19+	215
HB0903	Cetacean & Turtle Abund.	6 – 16 Aug	Offshore	SBE-19+	65
DEL0909	EcoMon Survey	17 – 29 Aug	MAB, GB	SBE-19+, 9/11	158
HB0904	Habitat Mapping	25 – 31 Aug	MAB	SBE-19+	29
HB0905	Fall Bottom Trawl	13 Sep – 19 Nov	Full Shelf	SBE-19+	363
DEL0910	Hydro Acoustic Survey	13 Sep – 15 Oct	GSC,GB,WGOM	SBE-19+	153
DEL0911	EcoMon Survey	3 – 20 Nov	Full Shelf	SBE-19+, 9/11	159

¹ Regional Abbreviation:
GSC=Great South Channel
GOM=Gulf of Maine
GB=Georges Bank
MAB=Mid Atlantic Bight

Table 2. The 2009 regional average surface and bottom temperature values computed from CTD data that were sorted into six 2-month time periods for the five regions of the Northeast U.S. continental shelf shown in Figure 1.

Region	CD	SURFACE						BOTTOM					
		#obs	Temp	Anomaly	SDV1	SDV2	Flag	#obs	Temp	Anomaly	SDV1	SDV2	Flag
January-February													
GOMW	42	29	4.64	-0.58	0.19	0.45	0	20	6.26	0.32	0.20	0.58	0
GOME	41	19	4.67	-0.82	0.22	1.05	1	11	6.86	-0.02	0.29	1.34	1
GB	37	38	4.89	-0.61	0.18	0.95	0	28	5.58	-0.25	0.20	1.18	0
MABN	32	33	5.83	-0.55	0.23	1.07	0	26	7.04	0.22	0.28	1.54	0
MABS	28	56	7.79	0.34	0.18	1.67	0	49	8.09	0.74	0.21	1.26	0
March-April													
GOMW	102	43	5.02	0.29	0.17	1.87	1	40	5.15	0.36	0.15	1.67	1
GOME	115	26	5.79	0.43	0.20	2.52	1	23	6.63	-0.68	0.21	2.33	1
GB	102	56	5.64	0.30	0.14	1.27	0	42	5.58	0.34	0.18	1.19	0
MABN	95	50	5.24	0.67	0.18	1.26	0	43	5.12	-0.49	0.22	1.70	0
MABS	72	89	6.90	1.09	0.14	1.37	0	76	6.71	1.05	0.17	1.73	0
May-June													
GOMW	146	51	9.78	0.52	0.16	1.03	0	49	5.61	0.17	0.15	0.88	0
GOME	149	38	8.54	0.32	0.18	1.03	0	32	6.86	-0.24	0.20	1.14	0
GB	162	65	11.17	0.91	0.14	1.63	0	55	8.25	-0.04	0.16	1.30	0
MABN	149	47	12.15	0.45	0.19	1.27	0	45	6.98	-0.39	0.21	1.24	0
MABS	145	105	15.19	0.28	0.14	1.15	0	99	9.36	0.28	0.15	1.56	0
July-August													
GOMW													
GOME													
GB	233	227	17.37	1.16	0.14	1.64	0	215	11.92	-0.28	0.17	2.61	0
MABN	232	26	23.17	2.73	0.23	2.05	0	22	11.17	1.15	0.31	1.70	0
MABS	232	62	25.81	2.00	0.17	1.18	0	42	10.91	-1.32	0.22	2.93	0
September-October													
GOMW	277	67	14.92	0.81	0.13	2.36	1	66	7.20	0.23	0.12	2.74	1
GOME	262	42	15.97	0.34	0.16	3.14	1	41	9.36	0.31	0.15	3.74	1
GB	291	80	14.20	-0.10	0.14	1.65	0	71	12.66	0.15	0.17	1.95	0
MABN	277	68	18.16	0.61	0.16	1.11	0	51	13.95	1.19	0.20	2.05	0
MABS	264	92	21.35	-0.14	0.14	1.09	0	70	17.20	3.02	0.18	2.75	0
November-December													
GOMW	317	58	10.61	0.62	0.15	0.82	0	52	7.92	0.64	0.14	1.07	0
GOME	314	44	11.29	0.37	0.15	1.49	1	39	8.59	0.15	0.16	1.95	1
GB	315	51	13.85	1.47	0.16	2.94	0	42	13.60	1.92	0.19	2.47	0
MABN	310	31	13.49	-0.50	0.23	0.74	0	27	13.84	0.79	0.28	1.12	0
MABS	311	46	15.17	-0.26	0.19	0.77	0	40	15.40	0.84	0.23	1.23	0

"Region", the geographic region of the northeast continental shelf. "CD", the calendar mid-date of all the stations within a region for a time period. "#obs", the number of observations included in each average. "Temp", the areal average temperature. "Anomaly", the areal average temperature anomalies. "SDV1", the standard deviation associated with the average temperature anomaly. "SDV2", the standard deviation of the individual anomalies from which the average anomaly was derived. "Flag", a value of "1" indicates that a true areal average could not be calculated due to poor station coverage. The areal averages listed were derived from a simple average of the observations within the region.

Table 3. The 2009 regional average surface and bottom salinity values computed from CTD data that were sorted into six 2-month time periods for the five regions of the Northeast U.S. continental shelf shown in Figure 1.

Region	CD	SURFACE						BOTTOM					
		#obs	Salt	Anomaly	SDV1	SDV2	Flag	#obs	Salt	Anomaly	SDV1	SDV2	Flag
January-February													
GOMW	42	29	32.92	-0.10	0.13	0.17	0	20	33.68	0.08	0.12	0.25	0
GOME	41	19	32.89	-0.16	0.15	0.43	1	11	34.05	-0.11	0.16	0.58	1
GB	37	38	32.65	-0.30	0.10	0.51	0	28	32.98	-0.11	0.12	0.46	0
MABN	32	32	32.79	-0.34	0.15	0.38	0	26	33.25	-0.32	0.16	0.62	0
MABS	28	55	33.24	-0.34	0.13	1.17	0	48	33.68	0.09	0.13	0.45	0
March-April													
GOMW	102	43	32.53	-0.14	0.11	0.76	1	40	33.20	-0.09	0.09	0.51	1
GOME	115	26	32.42	-0.14	0.13	1.03	1	23	34.25	-0.09	0.10	0.72	1
GB	102	56	32.84	-0.16	0.09	0.47	0	42	33.02	-0.14	0.11	0.35	0
MABN	85	50	32.69	-0.23	0.12	0.45	0	43	32.79	-0.70	0.13	0.52	0
MABS	72	89	32.95	-0.22	0.11	0.74	0	76	33.51	0.05	0.10	0.61	0
May-June													
GOMW	146	51	31.87	-0.29	0.11	0.38	0	49	33.21	-0.06	0.09	0.21	0
GOME	149	38	32.16	-0.17	0.12	0.33	0	32	33.84	-0.04	0.11	0.33	0
GB	162	65	32.66	-0.16	0.08	0.51	0	55	32.92	-0.12	0.10	0.25	0
MABN	149	47	32.17	-0.22	0.13	0.37	0	45	32.82	-0.33	0.12	0.31	0
MABS	145	105	32.09	-0.13	0.11	0.53	0	99	33.08	-0.23	0.10	0.68	0
July-August													
GOMW													
GOME													
GB	233	227	32.43	-0.34	0.08	0.28	0	215	32.69	-0.24	0.10	0.23	0
MABN	232	26	32.21	-0.36	0.15	0.80	0	22	33.24	0.01	0.18	0.51	0
MABS	232	62	30.99	-1.06	0.13	0.71	0	41	32.86	-0.25	0.13	0.48	0
September-October													
GOMW	277	67	31.97	-0.23	0.09	0.84	1	66	33.42	-0.03	0.07	0.50	1
GOME	262	42	32.21	-0.19	0.10	1.08	1	41	34.30	0.01	0.08	0.69	1
GB	291	80	32.78	0.05	0.08	0.60	0	71	32.91	-0.05	0.10	0.32	0
MABN	277	68	32.92	0.18	0.11	0.65	0	51	33.54	0.07	0.12	0.57	0
MABS	264	92	32.41	0.11	0.11	1.27	0	70	32.86	-0.41	0.11	1.06	0
November-December													
GOMW	317	58	32.57	-0.16	0.10	0.35	0	52	33.44	-0.18	0.08	0.37	0
GOME	314	44	32.41	-0.30	0.10	0.64	1	39	34.30	-0.16	0.08	0.65	1
GB	315	51	33.16	0.42	0.09	0.93	0	42	33.75	0.74	0.11	1.02	0
MABN	310	31	32.72	-0.20	0.16	0.82	0	27	33.57	0.05	0.16	0.62	0
MABS	311	46	32.82	-0.10	0.15	1.02	0	40	33.21	-0.17	0.14	0.74	0

"Region", the geographic region of the northeast continental shelf; "CD", the calendar mid-date of all the stations within a region for a time period; "#obs", the number of observations included in each average; "Salt", the areal average salinity; "Anomaly", the areal average salinity anomalies; "SDV1", the standard deviation associated with the average salinity anomaly; "SDV2", the standard deviation of the individual anomalies from which the average anomaly was derived; "Flag", a value of "1" indicates that a true areal average could not be calculated due to poor station coverage. The areal averages listed were derived from a simple average of the observations within the region.

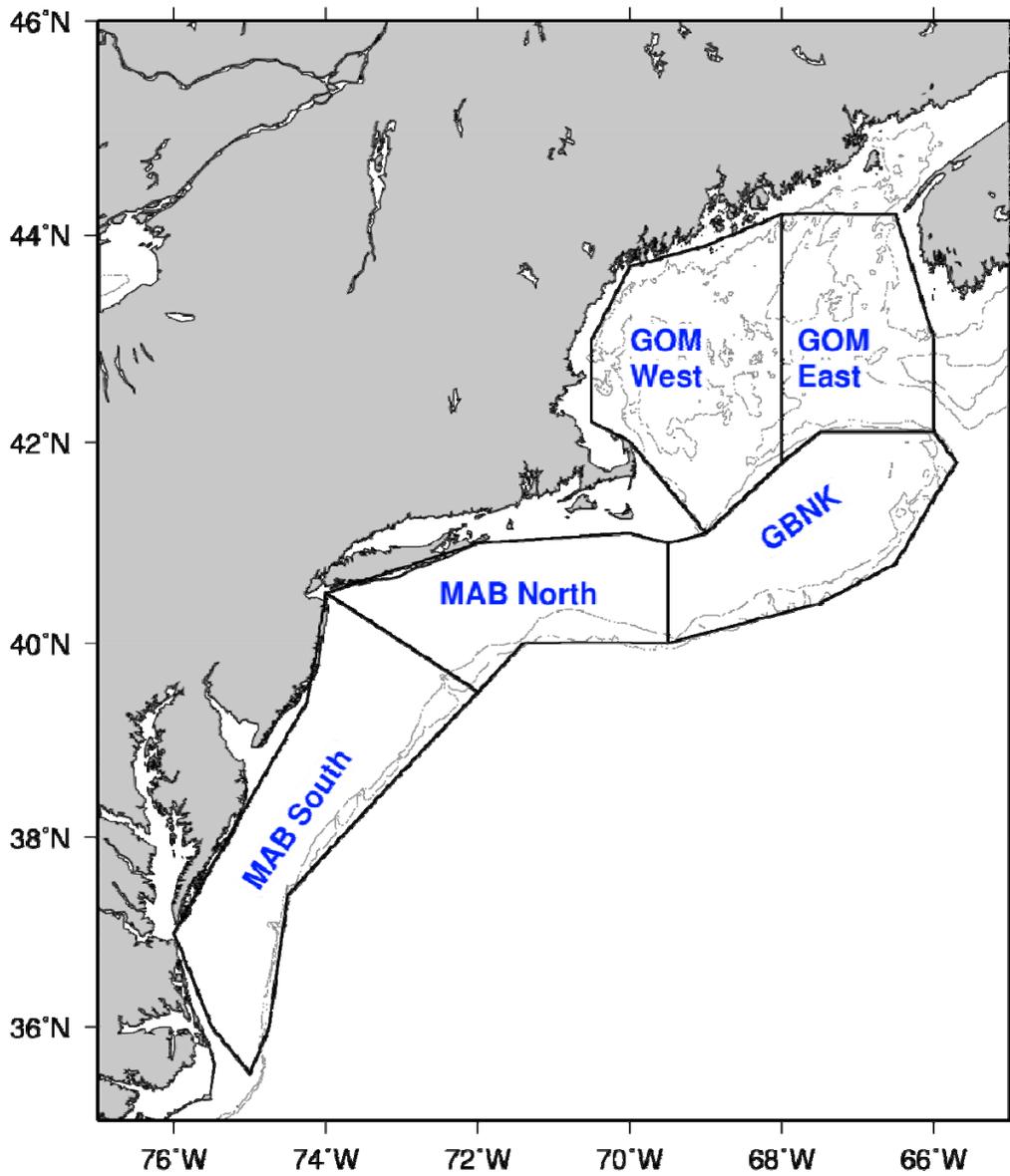


Figure 1. Region designations for the Northeast U.S. Continental Shelf. The 100 m and 200 m isobaths are also shown.

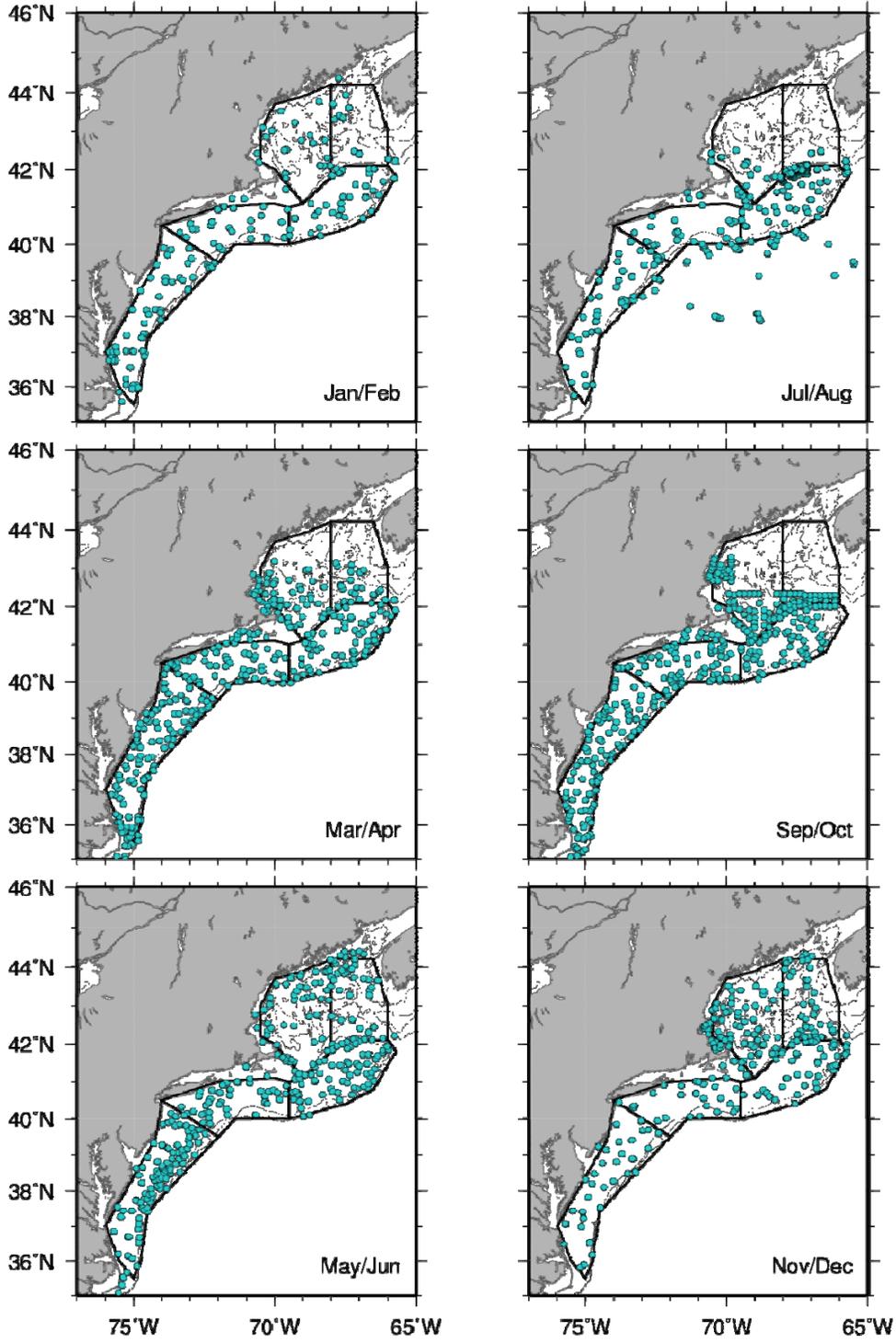


Figure 2. The 2009 station distributions for each 2-month time period. The regional boundaries are also overlain. Contours indicate the 100 and 200-meter isobaths.

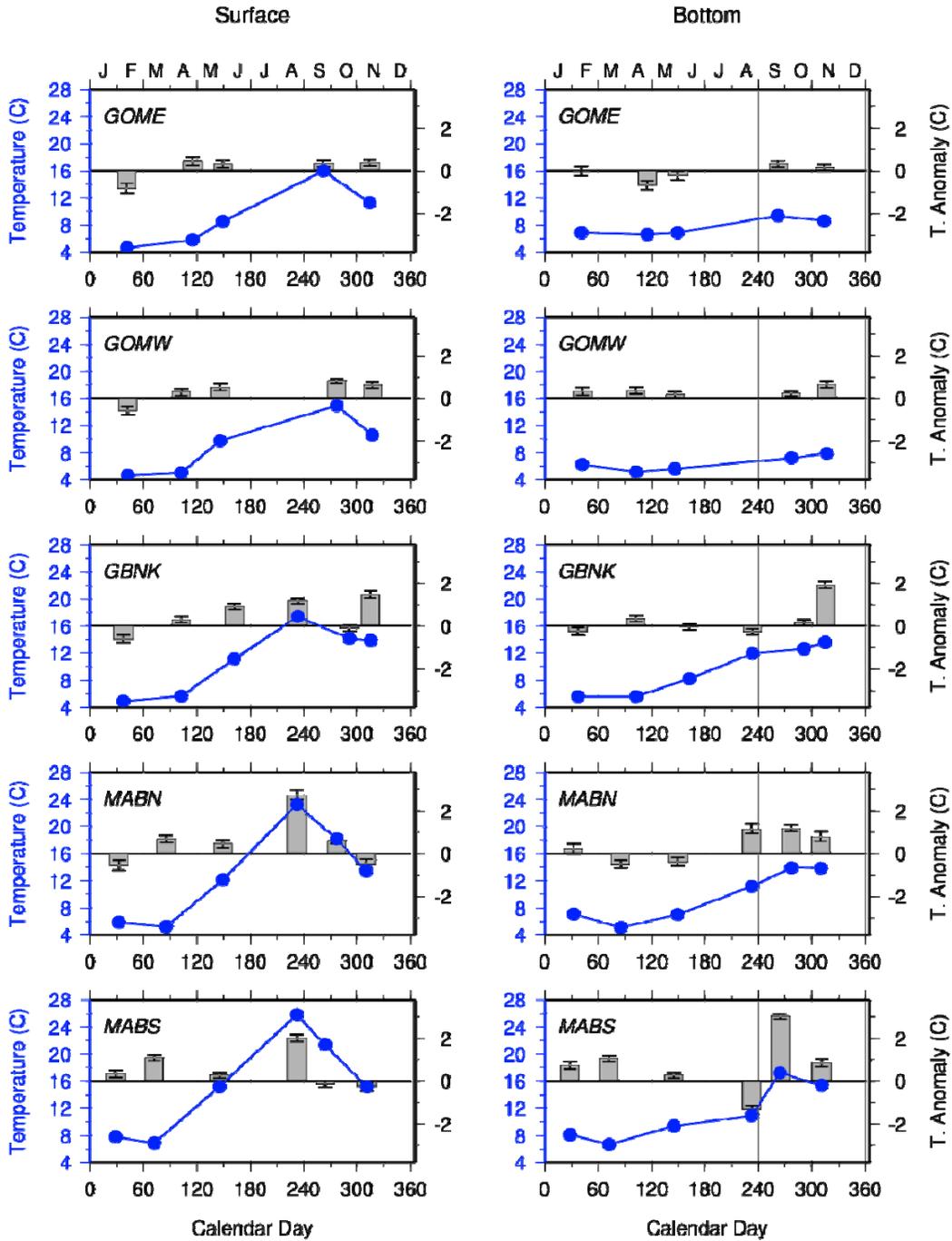


Figure 3. Time series of the 2009 regional surface (left) and bottom (right) temperatures (blue) and anomalies (bars) as a function of calendar day. Error bars are indicated for the anomaly estimates. The error bars are determined from SDV1 in Table 2, incorporating the uncertainty in both the predicted and measured temperatures from a given region (see Holzwarth and Mountain, 1990).

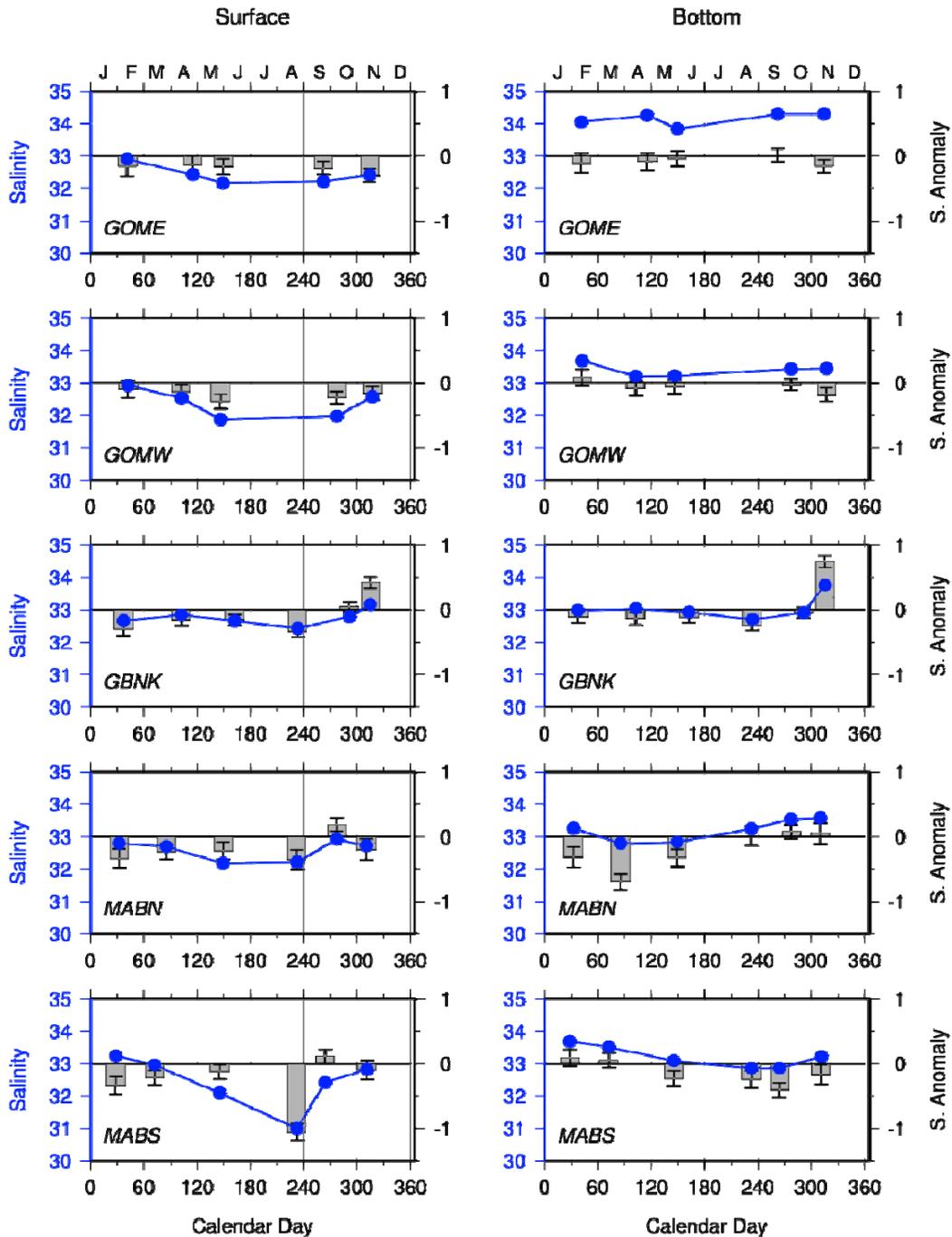


Figure 4. Time series of the 2009 regional surface (left) and bottom (right) salinities (blue) and anomalies (bars) as a function of calendar day. Error bars are indicated for the anomaly estimates. The error bars are determined from SDV1 in Table 3, incorporating the uncertainty in both the predicted and measured salinities from a given region (see Holzwarth and Mountain, 1990).

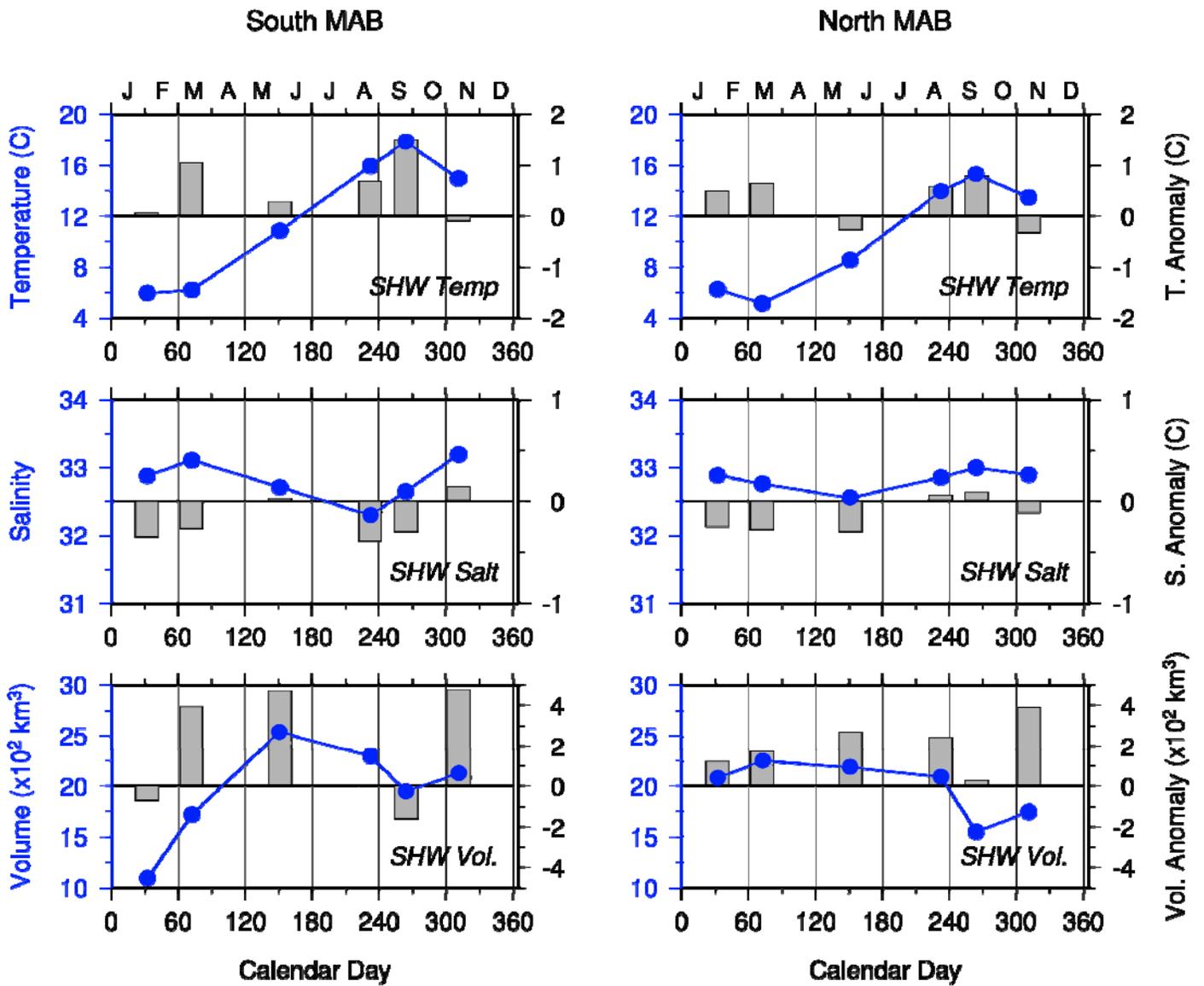


Figure 5. Time series of the 2009 regional shelf water temperature, salinity, and volume as a function of calendar day shown in blue for the southern (left) and northern (right) Middle Atlantic Bight. Shelf water anomalies are shown by the vertical bars.

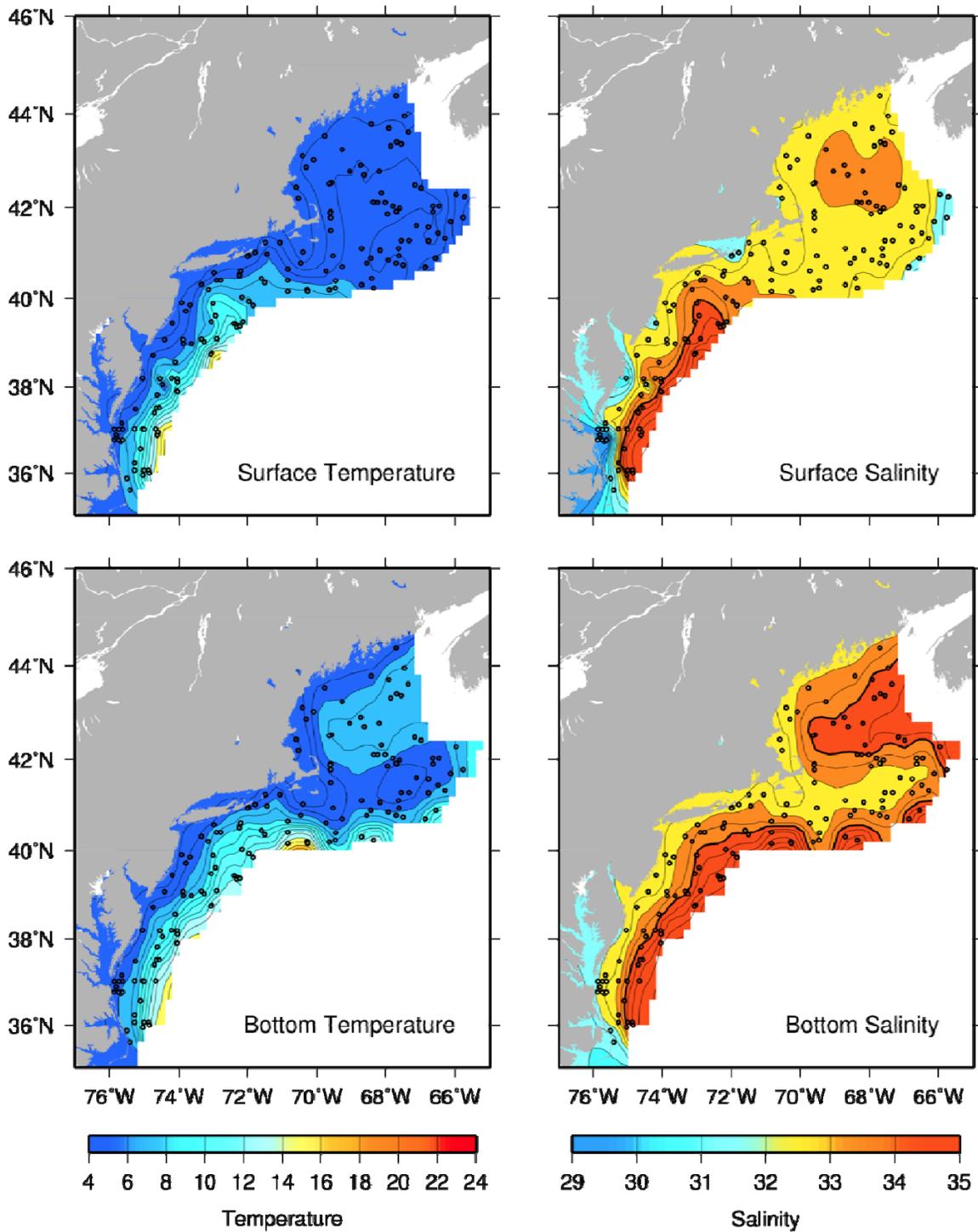


Figure 6a. Near-surface (top) and near-bottom (bottom) temperature (left) and salinity (right) distributions during January-February, 2009. Temperature and salinity are contoured in increments of 1°C and 0.5, respectively. The 34 isohaline is denoted by the heavier contour.

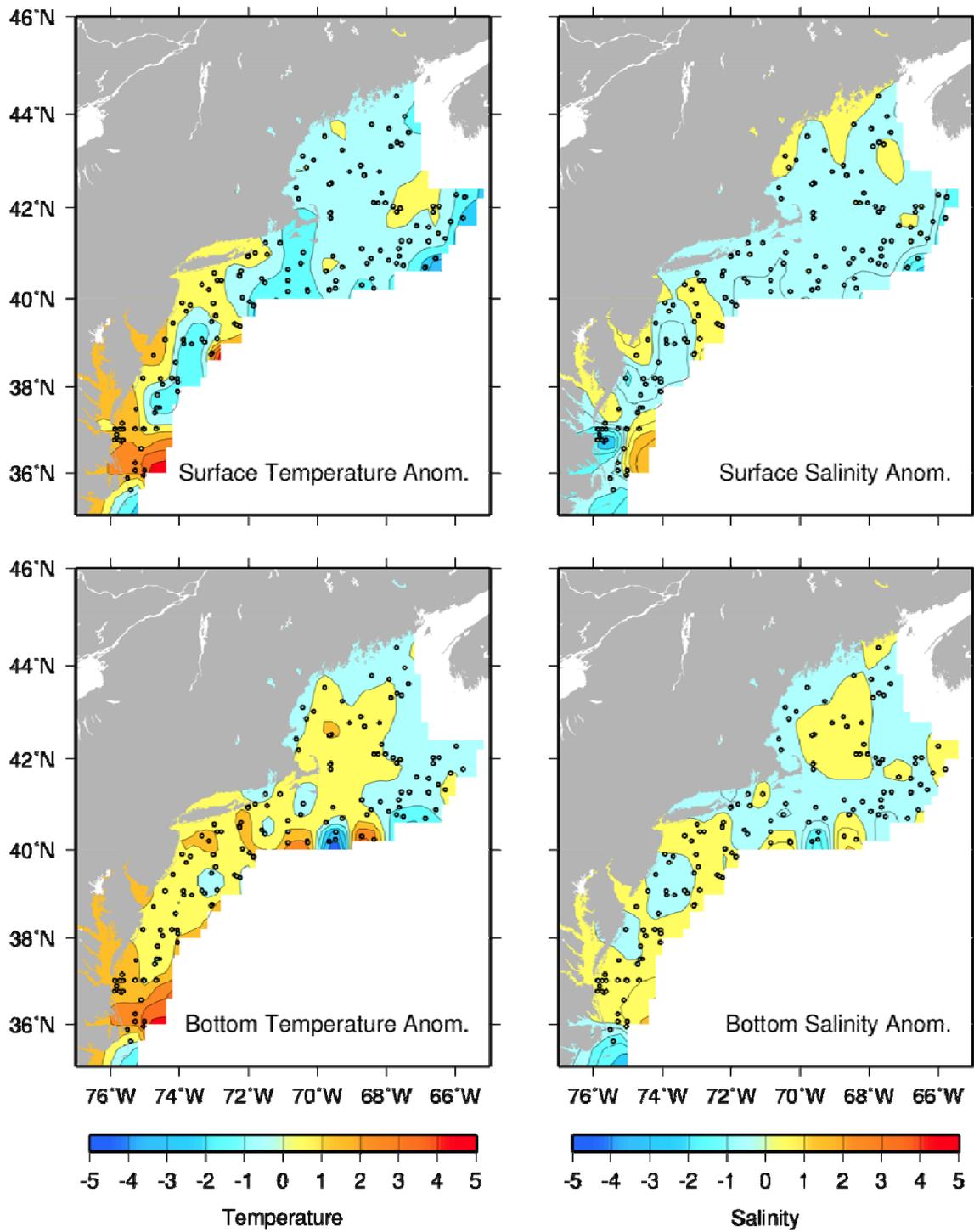


Figure 6b. Near-surface and near-bottom temperature anomaly (left) and salinity anomaly (right) distributions during January-February, 2009. Temperature and salinity anomaly are contoured in increments of 1°C and 0.5, respectively.

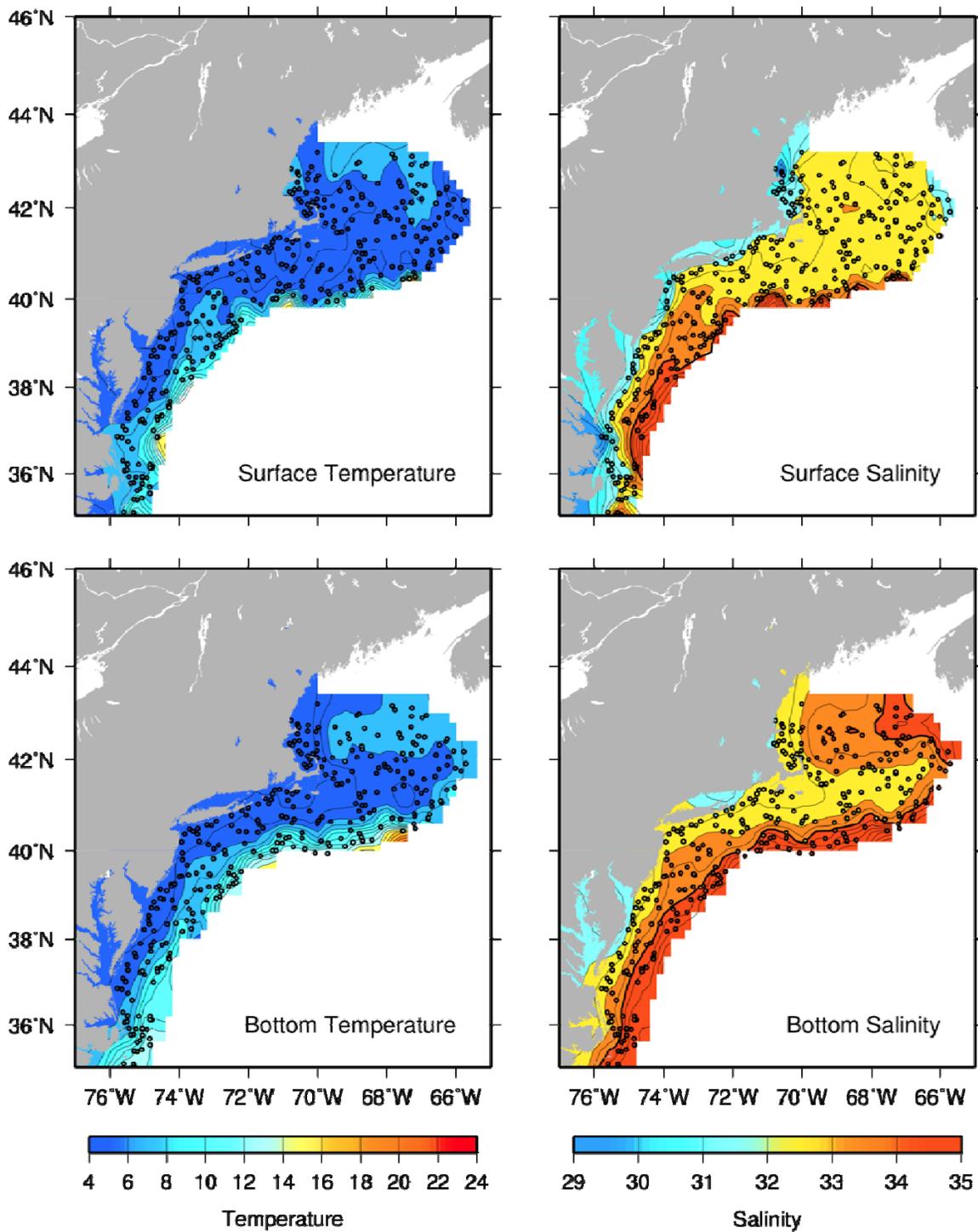


Figure 7a. Near-surface (top) and near-bottom (bottom) temperature (left) and salinity (right) distributions during March-April, 2009. Temperature and salinity are contoured in increments of 1°C and 0.5, respectively. The 34 isohaline is denoted by the heavier contour.

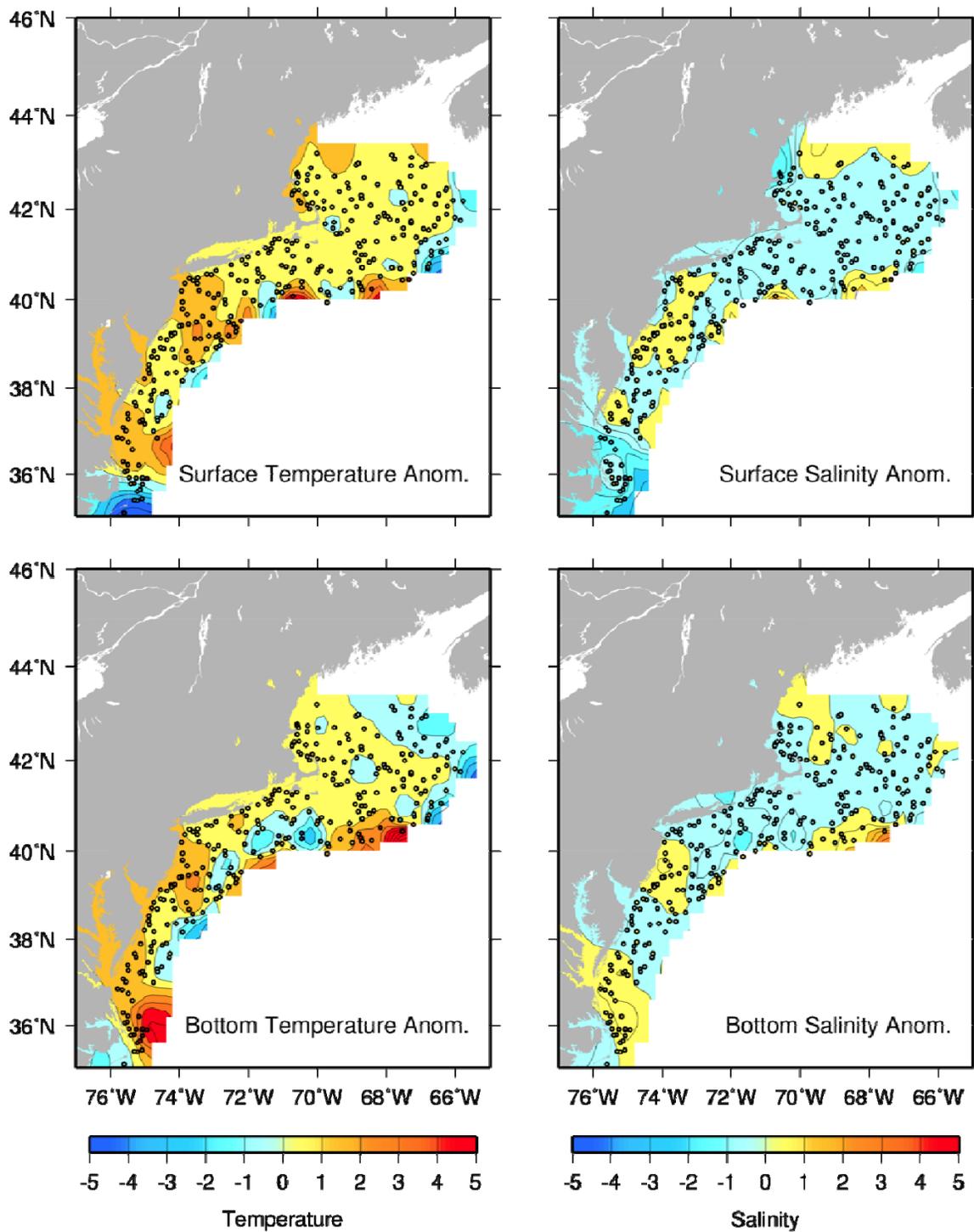


Figure 7b. Near-surface and near-bottom temperature anomaly (left) and salinity anomaly (right) distributions during March-April, 2009. Temperature and salinity anomaly are contoured in increments of 1°C and 0.5, respectively.

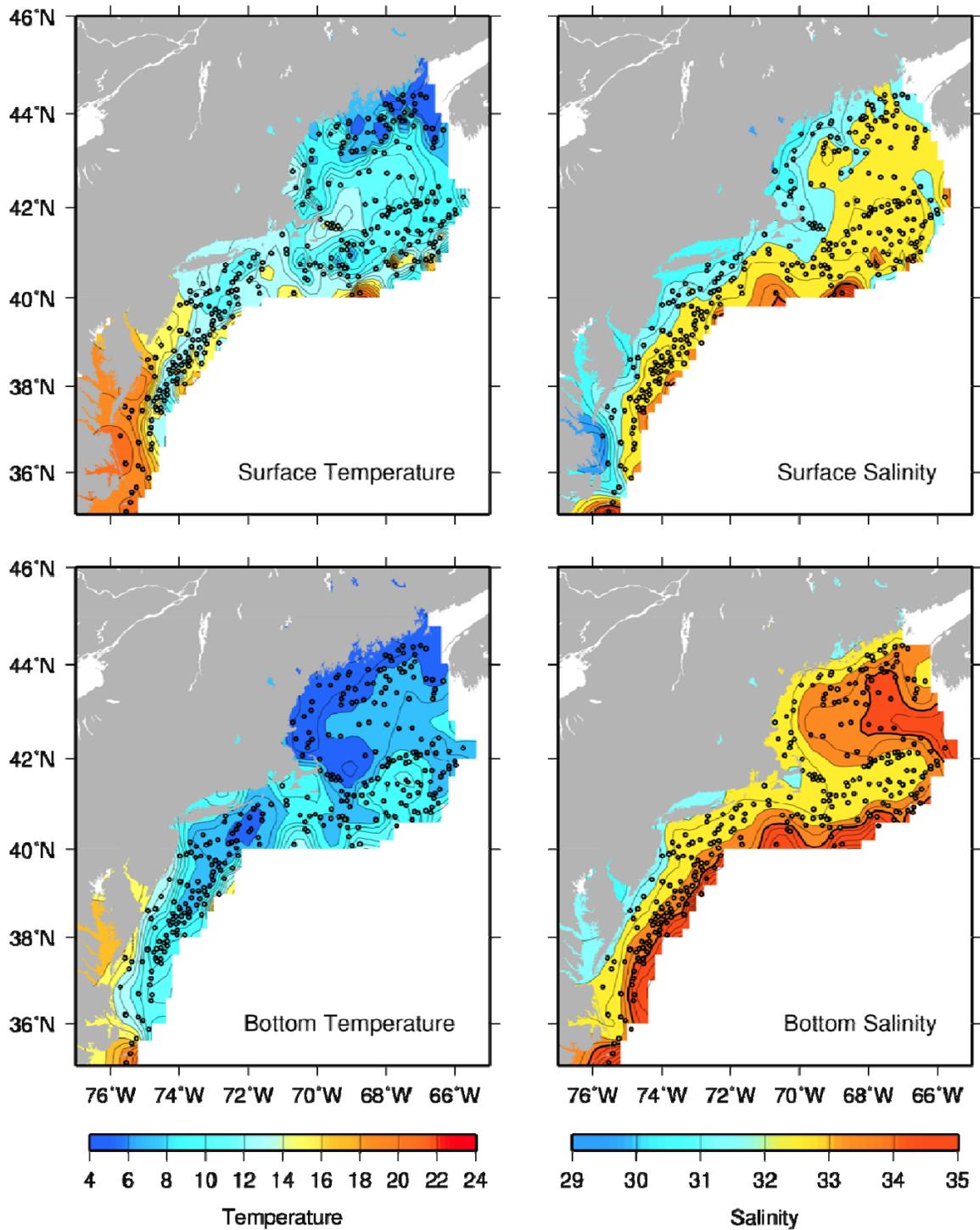


Figure 8a. Near-surface (top) and near-bottom (bottom) temperature (left) and salinity (right) distributions during May-June, 2009. Temperature and salinity are contoured in increments of 1°C and 0.5, respectively. The 34 isohaline is denoted by the heavier contour.

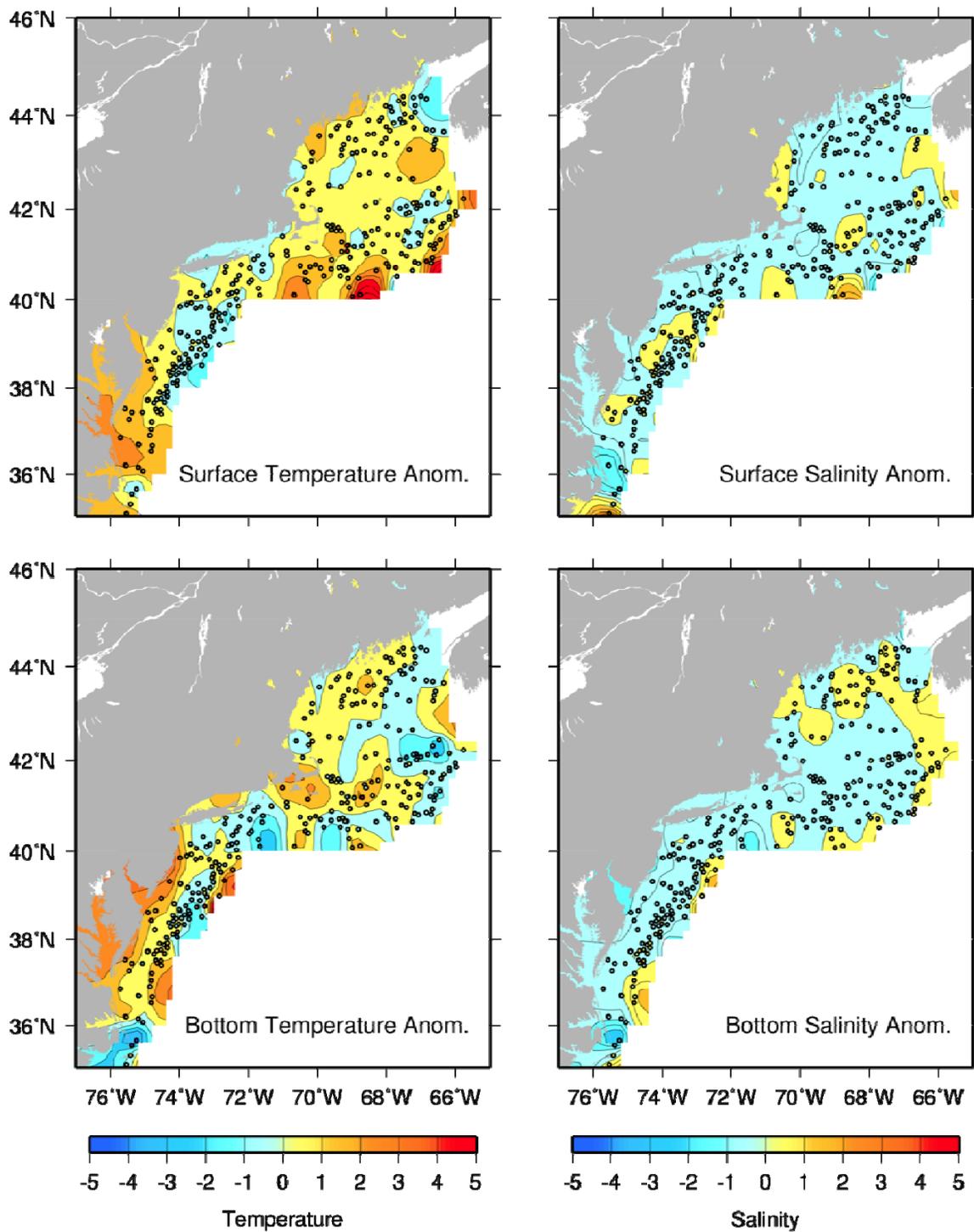


Figure 8b. Near-surface and near-bottom temperature anomaly (left) and salinity anomaly (right) distributions during May-June, 2009. Temperature and salinity anomaly are contoured in increments of 1°C and 0.5, respectively.

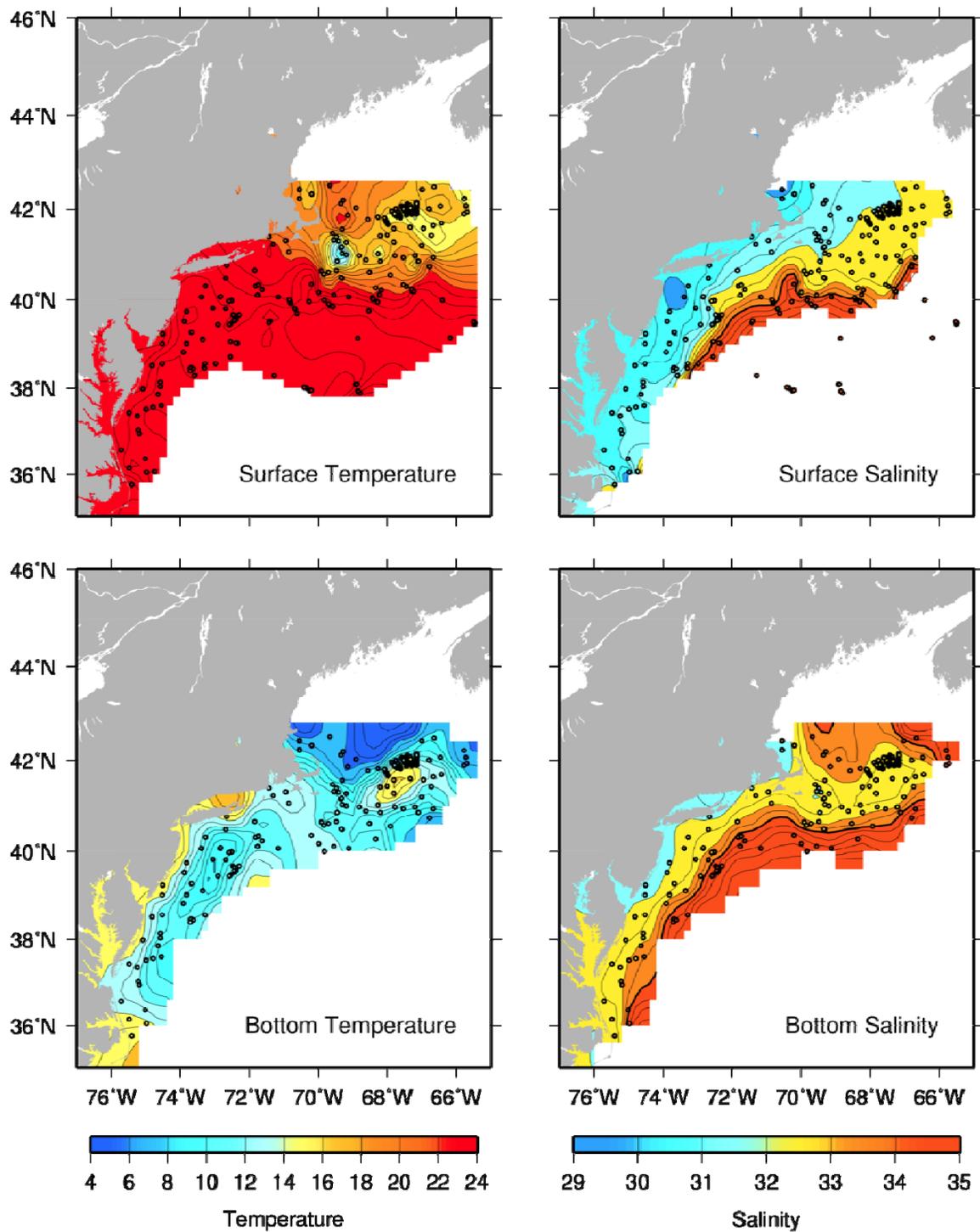


Figure 9a. Near-surface (top) and near-bottom (bottom) temperature (left) and salinity (right) distributions during July-August, 2009. Temperature and salinity are contoured in increments of 1°C and 0.5, respectively. The 34 isohaline is denoted by the heavier contour.

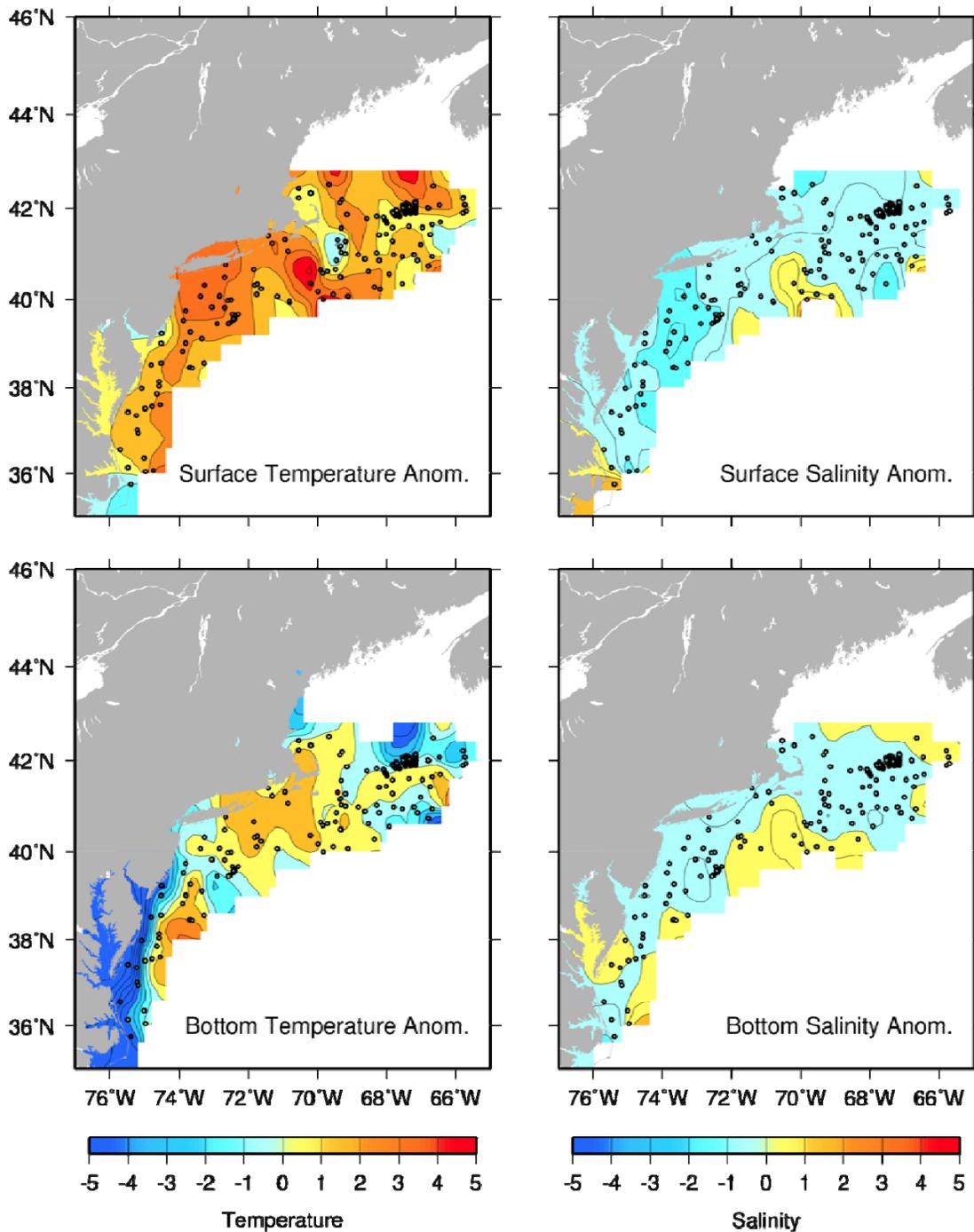


Figure 9b. Near-surface and near-bottom temperature anomaly (left) and salinity anomaly (right) distributions during July-August, 2009. Temperature and salinity anomaly are contoured in increments of 1°C and 0.5, respectively.

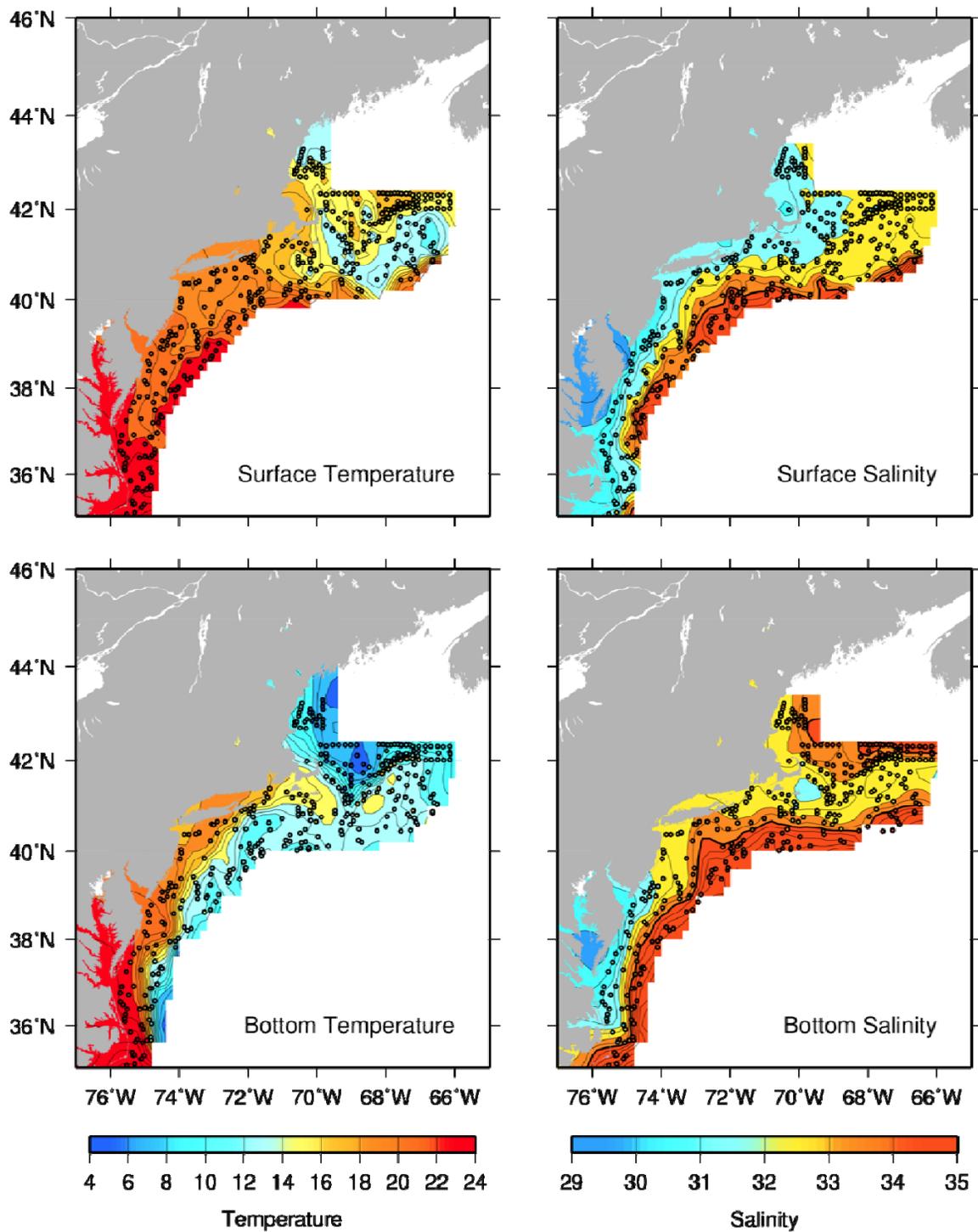


Figure 10a. Near-surface (top) and near-bottom (bottom) temperature (left) and salinity (right) distributions during September-October, 2009. Temperature and salinity are contoured in increments of 1°C and 0.5, respectively. The 34 isohaline is denoted by the heavier contour.

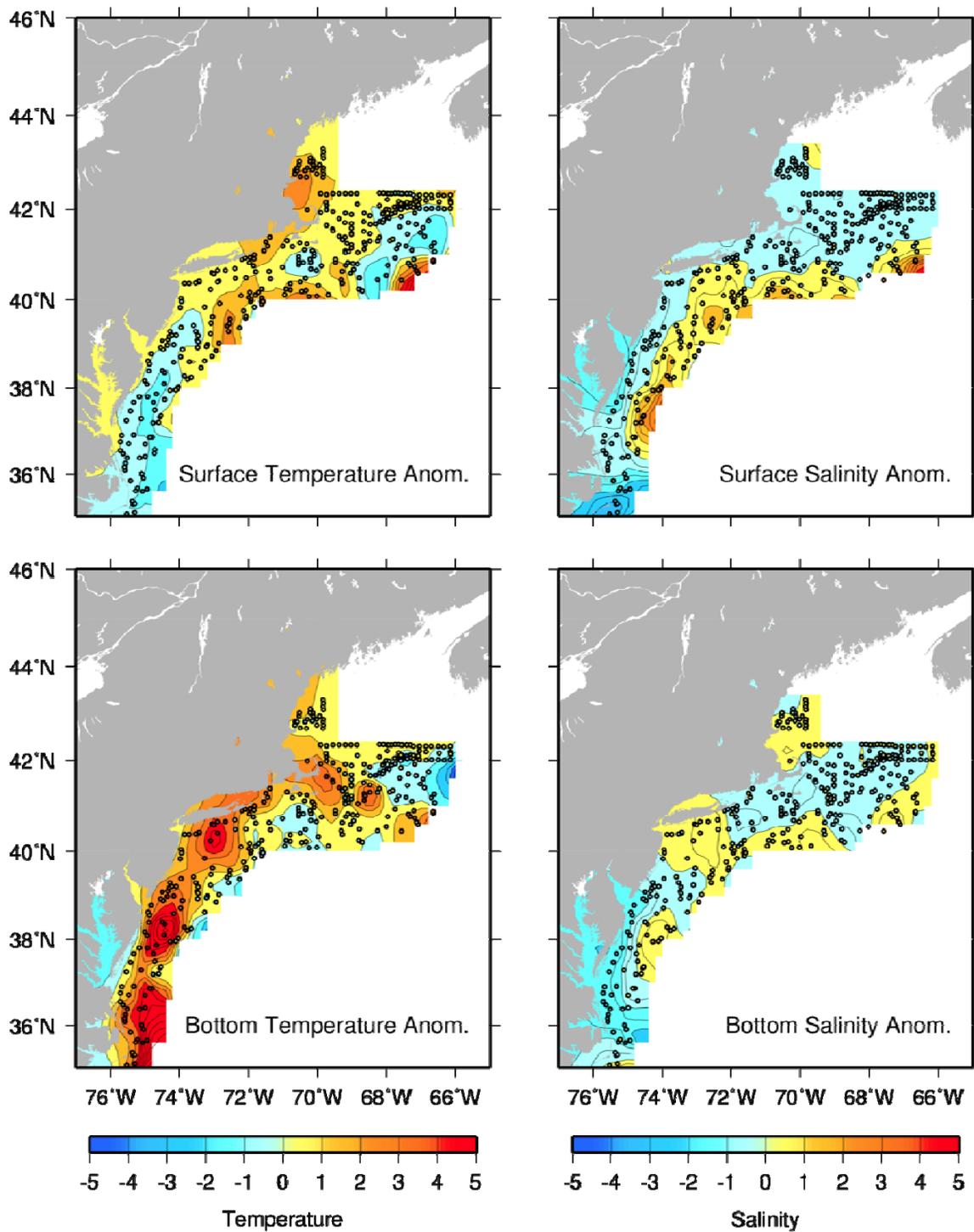


Figure 10b. Near-surface and near-bottom temperature anomaly (left) and salinity anomaly (right) distributions during September-October, 2009. Temperature and salinity anomaly are contoured in increments of 1°C and 0.5, respectively.

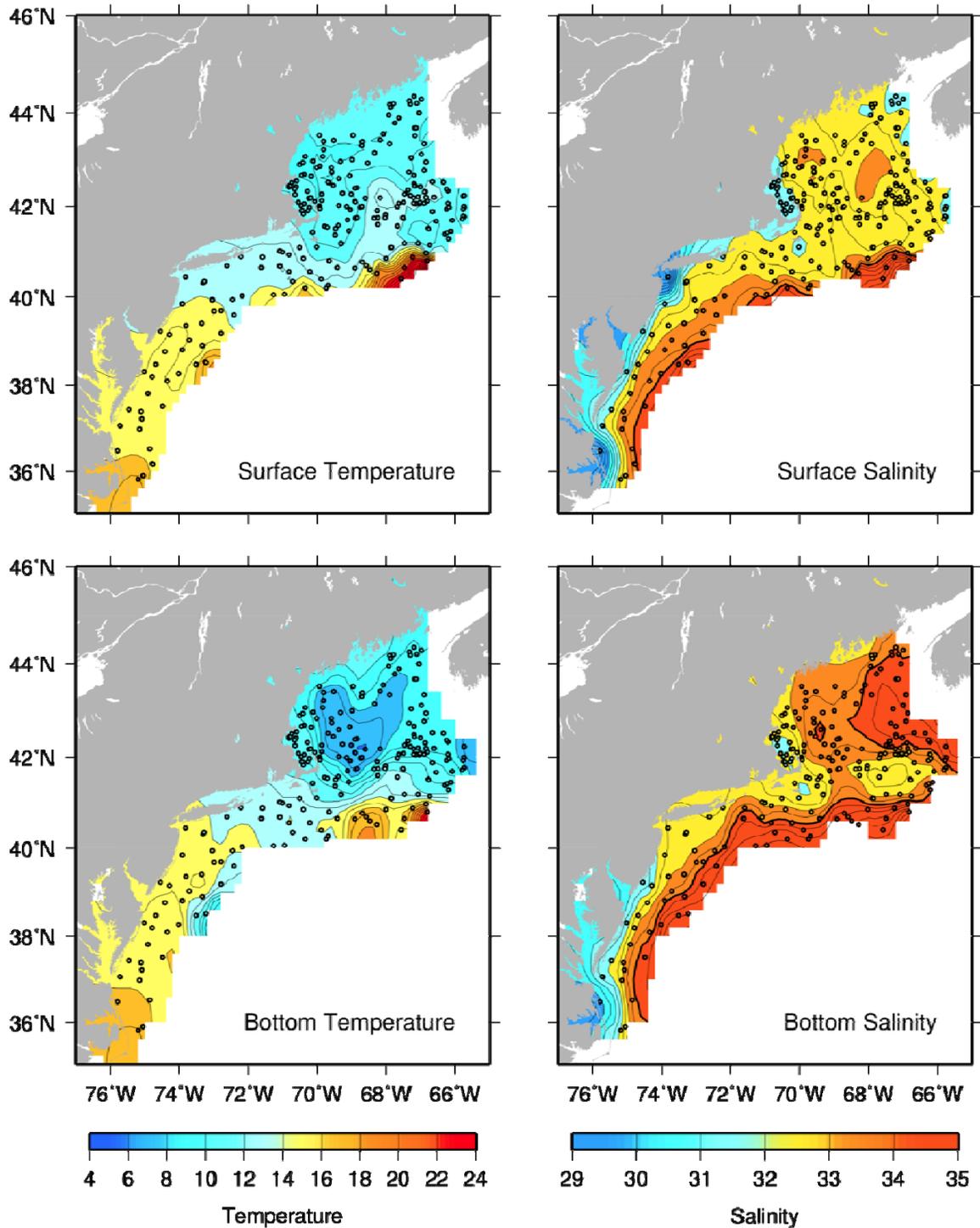


Figure 11a. Near-surface (top) and near-bottom (bottom) temperature (left) and salinity (right) distributions during November-December, 2009. Temperature and salinity are contoured in increments of 1°C and 0.5, respectively. The 34 isohaline is denoted by the heavier contour

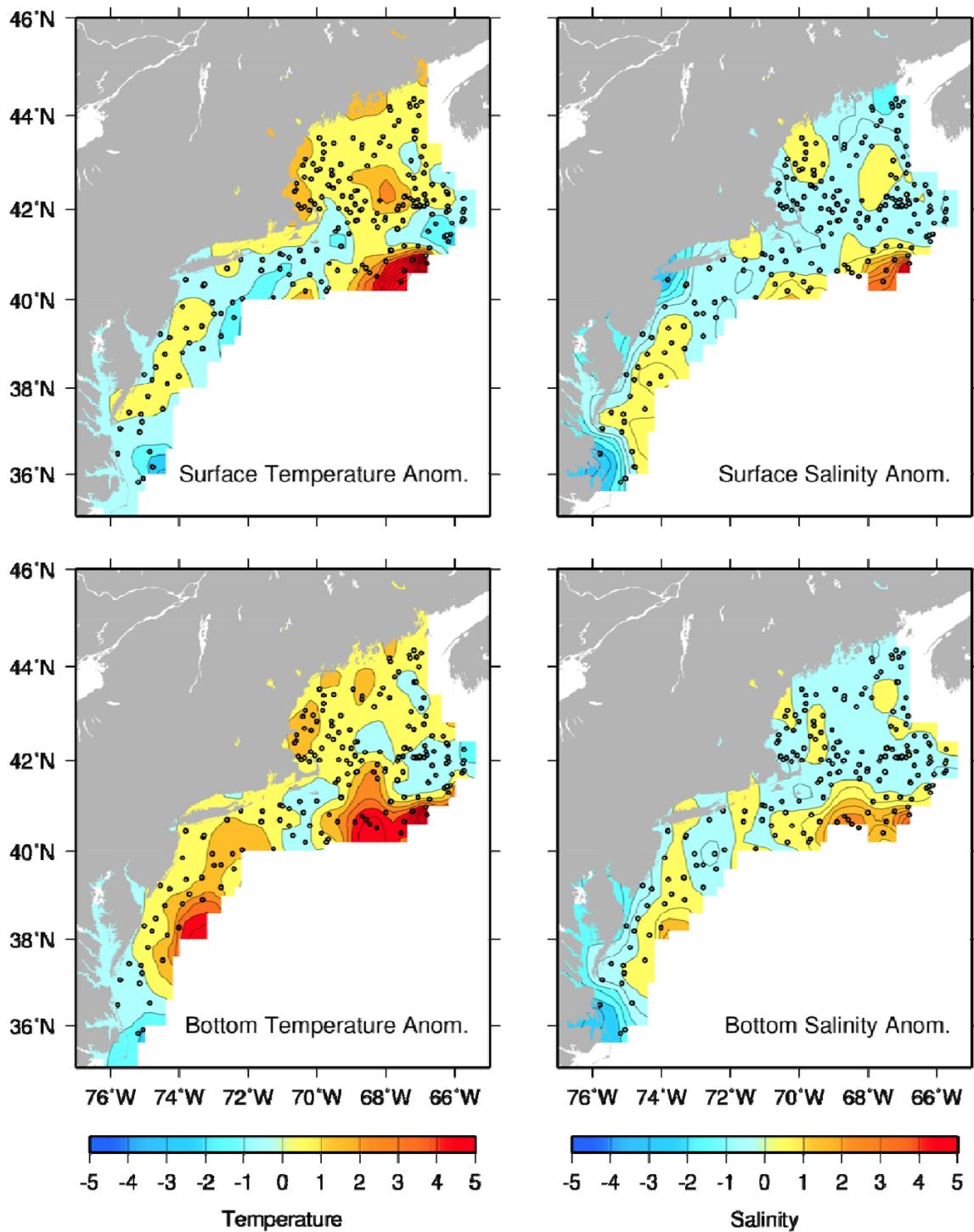


Figure 11b. Near-surface and near-bottom temperature anomaly (left) and salinity anomaly (right) distributions during for November-December, 2009. Temperature and salinity anomaly are contoured in increments of 1°C and 0.5, respectively.

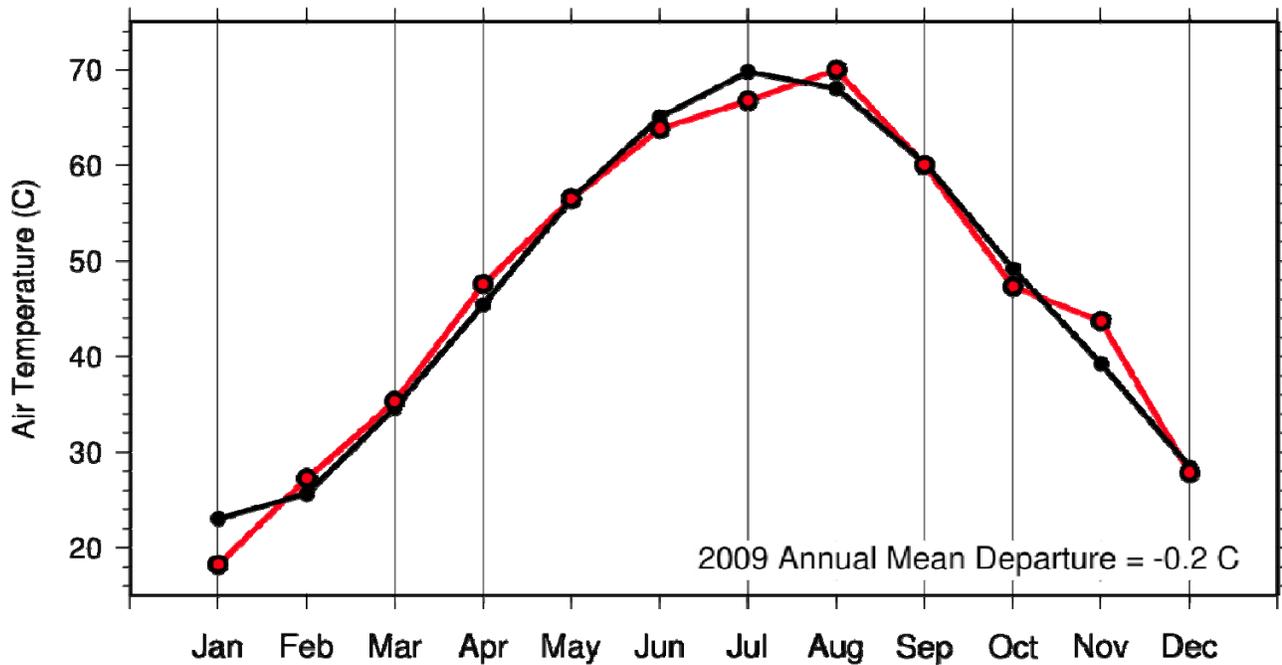


Figure 12. Monthly mean air temperature over the Northeastern U.S. for the years 1971-2000 (black) and 2009 (red), plotted from climate summary data compiled by the Northeast Regional Climate Center (<http://www.nrcc.cornell.edu>). The northeast region encompasses coastal states from Maine to Maryland and inland states west to West Virginia.

Appendix Table 1. The 2009 regional average temperature and salinity values for individual cruises that sampled within the western Gulf of Maine (boundaries defined in Figure 1.) Average values incorporating less than 10 observations are shown in gray.

Gulf of Maine West													
Cruise	CD	Surface						Bottom					
		#obs	Temp	Anomaly	SDV1	SDV2	Flag	#obs	Temp	Anomaly	SDV1	SDV2	Flag
DEL0902	42	29	4.64	-0.58	0.19	0.45	0	20	6.26	0.32	0.20	0.58	0
H80901	112	66	5.90	0.47	0.14	0.59	0	63	5.37	0.28	0.12	0.56	0
DEL0905	160	15	11.38	0.24	0.25	0.56	0	30	6.21	0.11	0.22	1.55	1
S10901	172	11	13.00	1.26	0.34	4.98	1	11	5.56	-0.27	0.34	3.90	1
DEL0907	202	6	16.54	-0.44	0.48	1.37	1	6	6.18	0.42	0.37	0.37	1
DEL0908	225	23	15.42	-0.49	0.18	3.41	1	23	13.32	-2.47	0.19	7.27	1
DEL0909	240	11	20.17	2.01	0.32	5.09	1	9	5.82	0.15	0.30	3.60	1
DEL0910	276	64	15.04	0.87	0.14	0.95	1	63	7.18	0.28	0.12	2.37	1
H80905	315	47	10.65	0.45	0.16	0.64	0	45	7.97	0.66	0.14	1.10	0
DEL0911	323	14	10.74	1.09	0.29	6.89	1	10	7.20	0.33	0.30	5.48	1

Cruise	CD	Surface						Bottom					
		#obs	Salinity	Anomaly	SDV1	SDV2	Flag	#obs	Salinity	Anomaly	SDV1	SDV2	Flag
DEL0902	42	29	32.92	-0.10	0.13	0.17	0	20	33.68	0.08	0.12	0.25	0
H80901	112	66	32.25	-0.26	0.09	0.55	0	63	33.29	-0.05	0.07	0.23	0
DEL0905	160	15	31.96	-0.16	0.16	0.24	0	30	33.31	-0.11	0.13	0.54	1
S10901	172	11	32.03	-0.12	0.19	1.12	1	11	32.56	-0.24	0.17	0.48	1
DEL0907	202	6	30.21	-1.16	0.31	0.45	1	6	32.12	-0.37	0.27	0.05	1
DEL0908	225	23	32.42	-0.09	0.12	0.52	1	23	32.50	-0.03	0.11	0.40	1
DEL0909	240	11	31.47	-0.55	0.20	1.09	1	9	33.54	-0.13	0.18	1.02	1
DEL0910	276	64	31.96	-0.22	0.09	0.25	1	63	33.44	-0.03	0.07	0.37	1
H80905	315	47	32.54	-0.19	0.10	0.33	0	45	33.41	-0.18	0.08	0.23	0
DEL0911	323	14	32.69	-0.04	0.18	2.22	1	10	33.47	-0.15	0.16	2.44	1

"Cruise", the code name for a cruise:
 CD, the calendar mid-date of all the stations within a region for that cruise:
 "#obs", the number of observations included in each average:
 "Temp", the areal average temperature: "Salt", the areal average salinity:
 Anomaly, the areal average temperature or salinity anomaly:
 "SDV1", the standard deviation associated with the average temperature or salinity anomaly:
 "SDV2", the standard deviation of the individual anomalies from which the average anomaly was derived:
 Flag, a value of "1" indicates that a true areal average could not be calculated due to poor station coverage.
 The areal averages listed were derived from a simple average of the observations within the region.

Appendix Table 2. The 2009 regional average temperature and salinity values for individual cruises that sampled within the eastern Gulf of Maine (boundaries defined in Figure 1.) Average values incorporating less than 10 observations are shown in gray.

Gulf of Maine East													
Cruise	Surface							Bottom					
	CD	#obs	Temp	Anomaly	SDV1	SDV2	Flag	#obs	Temp	Anomaly	SDV1	SDV2	Flag
DELO902	41	19	4.67	-0.82	0.22	1.05	1	11	6.86	-0.02	0.29	1.34	1
H80901	118	36	5.54	0.00	0.17	0.72	0	33	6.34	-0.53	0.18	0.72	0
DELO905	159	20	9.72	0.84	0.24	0.98	0	14	7.11	0.16	0.27	0.70	0
S10901	173	8	9.96	-0.16	0.35	7.55	1	8	7.38	-2.50	0.34	6.00	1
DELO908	221	64	16.71	2.42	0.12	2.88	1	63	9.19	-3.53	0.11	5.19	1
DELO909	239	6	16.38	1.37	0.44	15.26	1	4	7.51	0.40	0.50	-9.99	1
DELO910	262	42	15.97	0.34	0.16	1.45	1	41	9.36	0.31	0.15	3.19	1
H80905	312	35	11.05	0.01	0.16	1.11	1	33	8.69	0.19	0.17	2.08	1
DELO911	322	9	12.22	1.91	0.34	10.14	1	6	8.03	-0.09	0.39	8.26	1

Cruise	Surface							Bottom					
	CD	#obs	Salinity	Anomaly	SDV1	SDV2	Flag	#obs	Salinity	Anomaly	SDV1	SDV2	Flag
DELO902	41	19	32.89	-0.16	0.15	0.43	1	11	34.05	-0.11	0.16	0.58	1
H80901	118	36	32.26	-0.18	0.11	0.27	0	33	33.93	-0.17	0.09	0.31	0
DELO905	159	20	32.16	-0.11	0.18	0.42	0	14	34.05	0.11	0.16	0.22	0
S10901	173	8	32.63	-0.11	0.20	1.68	1	8	32.73	-0.05	0.20	0.74	1
DELO908	221	64	32.00	-0.51	0.07	0.41	1	63	32.59	-0.05	0.07	0.29	1
DELO909	239	6	32.35	0.01	0.28	3.26	1	4	33.87	0.07	0.24	-9.99	1
DELO910	262	42	32.21	-0.19	0.10	0.34	1	41	34.30	0.01	0.08	0.52	1
H80905	312	35	32.37	-0.36	0.12	0.64	1	33	34.26	-0.12	0.09	0.47	1
DELO911	322	9	32.57	0.00	0.22	3.27	1	6	34.50	-0.36	0.21	3.68	1

"Cruise", the code name for a cruise:
 CD, the calendar mid-date of all the stations within a region for that cruise:
 "#obs", the number of observations included in each average:
 "Temp", the areal average temperature: "Salt", the areal average salinity:
 Anomaly, the areal average temperature or salinity anomaly:
 "SDV1", the standard deviation associated with the average temperature or salinity anomaly:
 "SDV2", the standard deviation of the individual anomalies from which the average anomaly was derived:
 Flag, a value of "1" indicates that a true areal average could not be calculated due to poor station coverage.
 The areal averages listed were derived from a simple average of the observations within the region.

Appendix Table 3. The 2009 regional average temperature and salinity values for individual cruises that sampled within the Georges Bank area (boundaries defined in Figure 1.) Average values incorporating less than 10 observations are shown in gray.

Georges Bank													
Cruise	Surface							Bottom					
	CD	#obs	Temp	Anomaly	SDV1	SDV2	Flag	#obs	Temp	Anomaly	SDV1	SDV2	Flag
DEL0902	37	38	4.89	-0.61	0.18	0.95	0	28	5.58	-0.25	0.20	1.18	0
HB0901	103	60	5.71	0.29	0.14	1.23	0	46	5.63	0.33	0.18	1.15	0
DEL0905	156	33	10.55	0.63	0.20	1.20	0	24	8.32	0.12	0.25	0.88	0
S10901	173	30	12.30	1.09	0.21	2.12	0	29	8.19	-0.17	0.23	1.76	0
DEL0908	221	178	15.47	0.69	0.07	1.20	1	177	12.84	-1.28	0.07	2.44	1
HB0903	224	4	21.82	1.80	0.83	1.49	1	0					
DEL0909	237	45	17.32	1.13	0.16	1.80	0	38	12.10	-0.20	0.18	1.32	0
DEL0910	268	32	15.21	0.02	0.17	0.72	1	32	13.30	-0.34	0.17	2.80	1
HB0905	299	60	13.58	-0.27	0.14	1.86	0	48	12.26	0.03	0.17	1.37	0
DEL0911	317	39	13.84	1.64	0.17	3.18	0	33	13.68	2.07	0.20	2.37	0

Cruise	Surface							Bottom					
	CD	#obs	Salinity	Anomaly	SDV1	SDV2	Flag	#obs	Salinity	Anomaly	SDV1	SDV2	Flag
DEL0902	37	38	32.65	-0.30	0.10	0.51	0	28	32.98	-0.11	0.12	0.46	0
HB0901	103	60	32.83	-0.16	0.08	0.46	0	46	33.01	-0.14	0.11	0.34	0
DEL0905	156	33	32.55	-0.30	0.11	0.55	0	24	32.95	-0.11	0.15	0.31	0
S10901	173	30	32.69	-0.01	0.12	0.49	0	29	32.82	-0.21	0.14	0.22	0
DEL0908	221	178	32.23	-0.29	0.04	0.18	1	177	32.42	-0.16	0.04	0.14	1
HB0903	224	4	33.17	-0.55	0.53	0.91	1	0					
DEL0909	237	45	32.35	-0.33	0.10	0.38	0	38	32.70	-0.23	0.11	0.37	0
DEL0910	268	32	32.29	-0.22	0.10	0.19	1	32	32.49	-0.08	0.10	0.30	1
HB0905	299	60	32.80	0.03	0.09	0.68	0	48	32.92	-0.08	0.10	0.33	0
DEL0911	317	39	33.16	0.42	0.10	1.03	0	33	33.76	0.71	0.12	1.05	0

"Cruise", the code name for a cruise:
 CD, the calendar mid-date of all the stations within a region for that cruise:
 "#obs", the number of observations included in each average:
 "Temp", the areal average temperature: "Salt", the areal average salinity:
 Anomaly, the areal average temperature or salinity anomaly:
 "SDV1", the standard deviation associated with the average temperature or salinity anomaly:
 "SDV2", the standard deviation of the individual anomalies from which the average anomaly was derived:
 Flag, a value of "1" indicates that a true areal average could not be calculated due to poor station coverage.
 The areal averages listed were derived from a simple average of the observations within the region.

Appendix Table 4. The 2009 regional average temperature and salinity values for individual cruises that sampled within the northern Middle-Atlantic Bight (boundaries defined in Figure 1.) Average values incorporating less than 10 observations are shown in gray.

Northern Mid Atlantic Bight													
Cruise	Surface							Bottom					
	CD	#obs	Temp	Anomaly	SDV1	SDV2	Flag	#obs	Temp	Anomaly	SDV1	SDV2	Flag
DEL0902	31	28	5.83	-0.60	0.24	1.00	0	21	7.19	0.30	0.29	1.69	0
H80901	85	56	5.31	0.67	0.17	1.18	0	49	5.15	-0.50	0.22	1.61	0
S10901	148	15	11.84	0.42	0.32	2.18	1	15	6.02	-0.67	0.31	2.82	1
DEL0905	150	31	12.29	0.32	0.23	1.26	0	29	7.36	-0.23	0.25	1.63	0
H80903	228	2	23.90	0.86	1.14	-9.99	1	0					
DEL0909	233	24	23.16	3.00	0.27	2.29	0	22	11.17	1.13	0.31	1.51	0
H80904	237	1	24.75	2.60	1.46	-9.99	1	0					
H80905	276	59	18.23	0.66	0.17	1.05	0	42	13.96	1.23	0.22	2.06	0
DEL0910	286	9	15.41	-0.90	0.43	0.61	1	9	14.16	-0.06	0.43	1.19	1
DEL0911	310	31	13.49	-0.50	0.23	0.74	0	27	13.84	0.79	0.28	1.12	0

Cruise	Surface							Bottom					
	CD	#obs	Salinity	Anomaly	SDV1	SDV2	Flag	#obs	Salinity	Anomaly	SDV1	SDV2	Flag
DEL0902	31	27	32.81	-0.34	0.16	0.33	0	21	33.31	-0.27	0.17	0.61	0
H80901	85	56	32.69	-0.23	0.11	0.42	0	49	32.79	-0.70	0.12	0.51	0
S10901	148	15	31.70	-0.37	0.21	0.66	1	15	32.66	-0.27	0.19	1.06	1
DEL0905	150	31	32.21	-0.19	0.15	0.42	0	29	32.83	-0.34	0.15	0.40	0
H80903	228	2	33.47	-0.31	0.75	-9.99	1	0					
DEL0909	233	24	32.18	-0.24	0.17	0.76	0	22	33.24	0.01	0.18	0.52	0
H80904	237	1	33.25	0.18	0.97	-9.99	1	0					
H80905	276	59	32.93	0.19	0.11	0.64	0	42	33.57	0.08	0.13	0.58	0
DEL0910	286	9	32.06	-0.58	0.25	0.22	1	9	32.43	-0.45	0.25	0.42	1
DEL0911	310	31	32.72	-0.20	0.16	0.82	0	27	33.57	0.05	0.16	0.62	0

"Cruise", the code name for a cruise:
 CD, the calendar mid-date of all the stations within a region for that cruise:
 "#obs", the number of observations included in each average:
 "Temp", the areal average temperature: "Salt", the areal average salinity:
 Anomaly, the areal average temperature or salinity anomaly:
 "SDV1", the standard deviation associated with the average temperature or salinity anomaly:
 "SDV2", the standard deviation of the individual anomalies from which the average anomaly was derived:
 Flag, a value of "1" indicates that a true areal average could not be calculated due to poor station coverage.
 The areal averages listed were derived from a simple average of the observations within the region.

Appendix Table 5. The 2009 regional average temperature and salinity values for individual cruises that sampled within the southern Middle-Atlantic Bight, whose boundaries are defined in Figure 1. Average values incorporating less than 10 observations are shown in gray.

Southern Mid Atlantic Bight													
Cruise	Surface							Bottom					
	CD	#obs	Temp	Anomaly	SDV1	SDV2	Flag	#obs	Temp	Anomaly	SDV1	SDV2	Flag
DEL0901	18	22	10.30	0.71	0.30	1.27	1	15	10.37	1.26	0.37	1.79	1
DEL0902	32	39	7.20	0.19	0.22	1.78	0	35	7.54	0.52	0.26	1.21	0
HB0901	72	89	6.90	1.09	0.14	1.37	0	76	6.71	1.05	0.17	1.73	0
S10901	139	59	12.74	-0.29	0.17	1.02	1	58	7.94	0.19	0.18	1.37	1
DEL0905	151	46	16.28	0.39	0.20	1.17	0	42	10.25	0.49	0.21	1.45	1
HB0903	219	6	25.11	1.43	0.63	0.76	1	2	8.64	1.99	0.99	1.32	1
DEL0909	232	43	25.84	2.03	0.19	1.26	0	40	11.15	-1.54	0.21	3.06	1
HB0904	239	29	24.89	2.43	0.29	0.73	1	1	9.78	2.12	1.30	-9.99	1
HB0905	264	92	21.35	-0.14	0.14	1.09	0	70	17.20	3.02	0.18	2.75	0
DEL0911	311	46	15.17	-0.26	0.19	0.77	0	40	15.40	0.84	0.23	1.23	0

Cruise	Surface							Bottom					
	CD	#obs	Salinity	Anomaly	SDV1	SDV2	Flag	#obs	Salinity	Anomaly	SDV1	SDV2	Flag
DEL0901	18	21	34.25	0.04	0.22	0.44	1	14	34.29	0.29	0.22	0.46	1
DEL0902	32	39	33.07	-0.43	0.17	1.29	0	35	33.58	0.02	0.16	0.45	0
HB0901	72	89	32.95	-0.22	0.11	0.74	0	76	33.51	0.05	0.10	0.61	0
S10901	139	59	32.55	-0.07	0.12	0.30	1	58	33.51	-0.04	0.11	0.52	1
DEL0905	151	46	32.01	-0.11	0.16	0.69	0	42	32.60	-0.42	0.13	0.43	1
HB0903	219	6	31.98	-1.54	0.43	0.18	1	2	33.55	0.50	0.57	0.80	1
DEL0909	232	43	30.88	-1.04	0.15	0.70	0	39	32.79	-0.24	0.13	0.45	1
HB0904	239	29	32.32	-1.26	0.19	0.73	1	1	33.12	-0.35	0.76	-9.99	1
HB0905	264	92	32.41	0.11	0.11	1.27	0	70	32.86	-0.41	0.11	1.06	0
DEL0911	311	46	32.82	-0.10	0.15	1.02	0	40	33.21	-0.17	0.14	0.74	0

"Cruise", the code name for a cruise:
 CD, the calendar mid-date of all the stations within a region for that cruise:
 "#obs", the number of observations included in each average:
 "Temp", the areal average temperature: "Salt", the areal average salinity:
 Anomaly, the areal average temperature or salinity anomaly:
 "SDV1", the standard deviation associated with the average temperature or salinity anomaly:
 "SDV2", the standard deviation of the individual anomalies from which the average anomaly was derived:
 Flag, a value of "1" indicates that a true areal average could not be calculated due to poor station coverage.
 The areal averages listed were derived from a simple average of the observations within the region.

Appendix Table 6. The 2009 temperature, salinity and volume of the shelf water in the Middle-Atlantic Bight during 2009. The shelf water is defined as water within the upper 100 meters having salinity less than 34.

CD	Temp	Temp. Anomaly	Salt	Salt Anomaly	SHW Temp	SHW T. Anom	SHW Salt	SHW S. Anom	SHW Volume	SHW Vol. Anomaly
MABN										
31	7.42	0.47	33.26	-0.3	6.28	0.49	32.89	-0.25	2075.22	118.96
85	5.81	0.23	32.99	-0.34	5.14	0.63	32.76	-0.28	2247.54	171.79
150	9.21	-0.27	32.88	-0.38	8.55	-0.27	32.55	-0.3	2185.27	265.35
233	14.31	0.5	33.16	-0.3	13.96	0.58	32.86	0.06	2088.66	238.75
276	15.91	0.94	33.69	0.04	15.32	0.78	33	0.09	1546.93	28.56
310	14.14	-0.23	33.49	-0.23	13.46	-0.33	32.9	-0.11	1745.06	387.07
MABS										
32	8.9	-0.14	34.05	-0.14	5.96	0.06	32.88	-0.35	1094.44	-69.61
72	8.14	0.22	33.85	-0.12	6.23	1.04	33.11	-0.27	1720.13	390.97
151	10.94	-0.07	33.03	-0.31	10.87	0.28	32.71	0.03	2538.19	469.41
232	15.81	-0.22	33.01	-0.3	15.93	0.69	32.3	-0.39	2296	-4.36
264	17.76	1.35	33.51	-0.02	17.82	1.49	32.65	-0.3	1941.84	-161.04
311	15.31	0.53	33.66	-0.27	14.96	-0.09	33.19	0.14	2126.31	476

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